

# **Methods and guidance to support MRV of livestock emissions**

**Methods for data collection, analysis and summary results from a pilot baseline survey for the Kenya dairy NAMA**

Working Paper No. 285

CGIAR Research Program on Climate Change,  
Agriculture and Food Security (CCAFS)

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RESEARCH PROGRAM ON  
**Climate Change,  
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Working Paper

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## Abstract

There is increasing interest in mitigation of greenhouse gas (GHG) emissions from the dairy sector in developing countries. However, there is little prior experience with measurement, reporting and verification (MRV) of GHG emissions and emission reductions. A voluntary carbon market methodology, the Smallholder Dairy Methodology, has proposed a methodology for establishing a standardized performance baseline for a region targeted by a GHG mitigation initiative. This working paper reports the first experience of implementing a survey and analyzing survey data to establish a standardized performance baseline using survey data from central Kenya, which is a region targeted by the Kenya dairy NAMA promoted by the Government of Kenya. The publication of this report enables transparent documentation of the baseline setting process for the Kenya dairy NAMA. Data from the survey were also used to characterize dairy production in the intensive production system in Kenya's Tier 2 GHG inventory for dairy cattle. Publication of the survey data also supports transparency of Kenya's Tier 2 GHG inventory. The report summarizes the requirements of the Smallholder Dairy Methodology, the methods used for sampling, data collection and data analysis, the main results of data analysis and recommendations for future similar initiatives to quantify standardized baselines for dairy GHG mitigation programs. Appendices present data collection tools, summary statistics, and the data used to estimate parameters in Kenya's Tier 2 dairy GHG inventory. Analysis of the survey data following the Smallholder Dairy Methodology's requirements shows that the relationship between GHG intensity (kg CO<sub>2</sub>e/kg fat and protein corrected milk [FPCM]) and milk yield (kg FPCM per farm per year) can be represented by a power regression:  $y = 81.868x^{-0.436}$ . Using this relationship, dairy initiatives in central Kenya need only to measure change in milk yield per farm per year, and can estimate GHG emissions and emission reductions using the relationship published here. The regression has an  $r^2$  of 0.43, and an uncertainty of 18.6% as measured by the root mean square error (RMSE) of the regression. The Smallholder Dairy Methodology does not require quantification of uncertainty, but other mitigation initiatives may use estimated uncertainty to discount the GHG emission reductions claimed in order to ensure conservativeness. The baseline survey is representative of 8 counties with a dairy cattle population of about 1.7 million, and data collection and analysis cost about US\$ 75,000. The methodology is therefore a cost-effective way to set baselines for an initiative with large numbers of participating farms.

**Keywords**

Dairy; Greenhouse gas emissions; Kenya; Methodology

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## Acronyms

AFC	age at first calving
ANOVA	analysis of variance
$C_a$	coefficient for activity
CAN	calcium ammonium nitrate
CDM	Clean Development Mechanism
$C_f$	coefficient for maintenance
$C_p$	coefficient for pregnancy
CP	crude protein
DAP	diammonium phosphate
DE	digestible energy
d.f.	degrees of freedom
DMA	dry matter feed available
DMI	dry matter intake
EF	emission factor
FPCM	fat and protein corrected milk
GE	gross energy
GHG	greenhouse gas
GHGI	greenhouse gas emission intensity
GIS	geographic information system
HG	hearth girth
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization

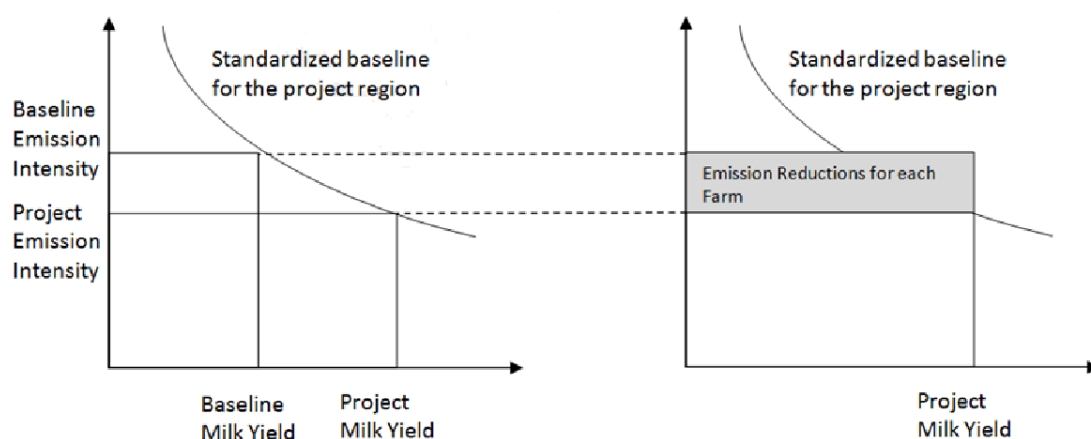
LCA	life cycle assessment
LW	liveweight
MAR	missing at random
MCAR	missing completely at random
MCF	methane conversion factor
MJ	megajoule
MMS	manure management system
MRV	measurement, reporting and verification
MS	Microsoft
MW	manure weight
NAMA	nationally appropriate mitigation action
OM	operating margin
PMM	predictive mean matching
RSME	root mean square error
SNV	Netherlands Development Organisation
SSP	single superphosphate
TMR	total mixed ration
TSP	triple super phosphate
UN FAO	Food and Agriculture Organization of the United Nations
US	United States
VS	volatile solids
WG	weight gain

# 1. Introduction

Dairy cattle make significant contributions to global greenhouse gas (GHG) emissions (Smith et al. 2014, Tubiello et al. 2014). With increasing global demand for livestock products, including dairy products, there is growing interest in measures to meet consumption demand while minimizing the impact on the global environment (Gerber et al. 2013, Herrero et al. 2016, Mottet et al. 2017). Forty-eight developing countries have included the livestock sector in their Nationally Determined Contributions (NDCs), and several countries have proposed specific mitigation actions (Wilkes et al. 2017). In addition, development banks and other actors are exploring ways to leverage finance for investment in dairy development by recognizing the climate change mitigation effects of more efficient dairy production (World Bank and FAO 2019).

All these initiatives require that the mitigation effects of dairy development can be quantified. Intensive data collection for baselines and monitoring, and the transaction costs associated with large numbers of farmers have been identified as barriers to engagement of the agriculture sector in carbon markets, such as the Clean Development Mechanism (CDM) (Larson et al. 2011). Standardized baselines have been introduced in the CDM as a way of reducing transaction costs for underrepresented sectors such as agriculture (Spalding-Fecher and Michaelowa 2013).

**Figure 1: Schematic illustration of the role of a standardized baseline in estimation of project emission reductions**



In 2016, the Gold Standard—a voluntary carbon standard—approved a GHG quantification methodology for road-testing that had been developed by a consortium led by UN FAO (Gold Standard and FAO 2016). The Smallholder Dairy Methodology seeks to reduce the costs of measuring GHG emissions and emission reductions in smallholder dairy systems by estimating baseline emissions from smallholder dairy farms using the results of a survey conducted in the target region of the dairy development intervention. The regional survey establishes a standardized baseline for the region in terms of a relationship between milk yield per farm (kg fat and protein corrected milk, kg FPCM) and the GHG intensity of each kg of milk produced ( $\text{kgCO}_2\text{e kg FPCM}^{-1}$ ) for each farm, as illustrated in Figure 1. To monitor the effects of dairy development interventions on GHG emissions in the target region, it is only necessary to then measure change in milk yield on participating farms. Emission reductions are calculated as the difference between the project scenario milk yield at the project scenario GHG emission intensity and project scenario milk yield at the baseline emission intensity for each farm. While a dedicated effort is required to collect and analyze data with which to establish the standardized baseline, additional monitoring costs for GHG

quantification purposes are minimized as monitoring milk yield is a standard practice in dairy development interventions.

The Government of Kenya has proposed a nationally appropriate mitigation action (NAMA) for the dairy sector (State Department of Livestock 2017). Kenya's Dairy NAMA proposes to use the Smallholder Dairy Methodology to measure GHG emission reductions from dairy development interventions. To test the practical feasibility of the methodology, a pilot baseline survey was conducted in central Kenya, a region dominated by intensive dairy cattle production. The intention is that the field-tested methods can then be replicated in other regions of the country, ultimately providing standardized baselines with nationwide coverage for the dairy NAMA. Similar initiatives are also being developed in other developing countries and these methods may be adopted for use elsewhere.

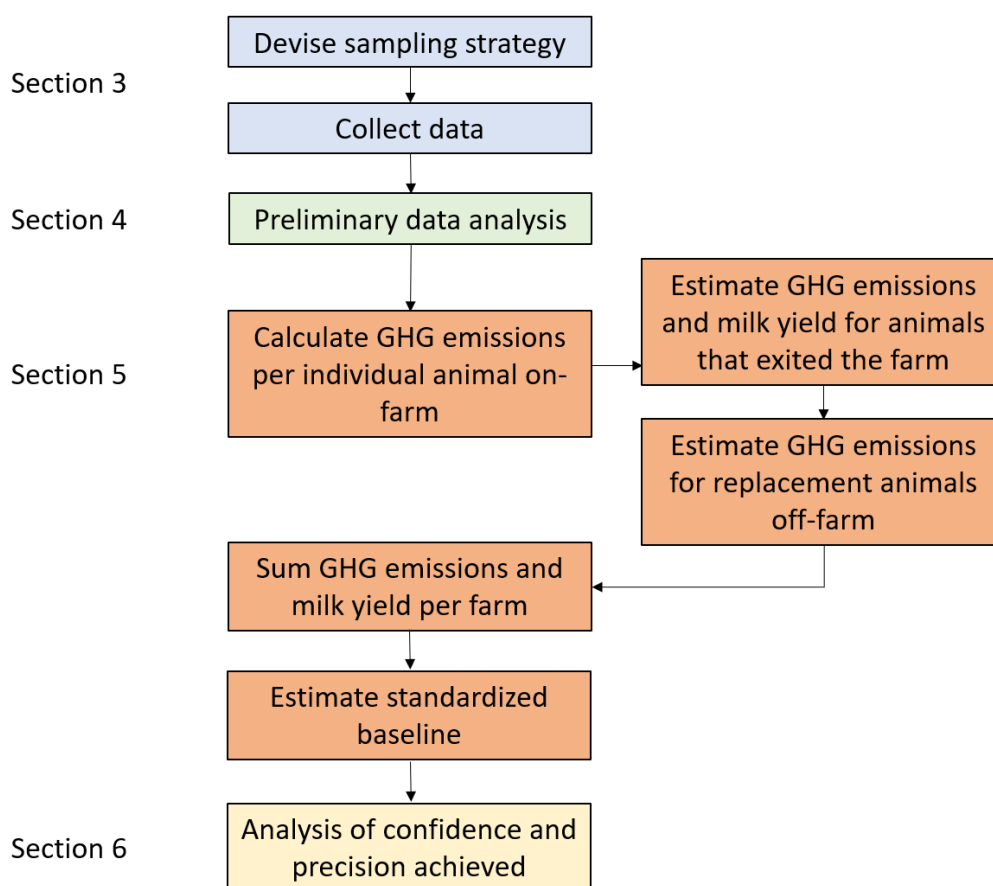
The descriptive results of the pilot baseline survey were also used as the main data source to estimate dairy cattle characteristics and performance in the intensive dairy production system represented in Kenya's national GHG inventory (State Department of Livestock 2019). Publishing the data collection methods used and the summary results increases the transparency of the Dairy NAMA Measurement, Reporting and Verification (MRV) system and the national GHG inventory. By documenting the methods used in the Kenya baseline survey, this report can also serve as a reference for similar activities elsewhere.

This report is structured as follows: Section 2 gives an overview of the Smallholder Dairy Methodology's requirements and the process used to estimate a standardized baseline for one region in Kenya. Section 3 describes the methods used for sampling and data collection. Section 4 describes the methods used to process the data, including treatment of missing values, and preliminary data analysis. Section 5 describes the methods used to transform the data into estimates of parameter values required by the Smallholder Dairy Methodology. Section 6 summarizes the key lessons from the baseline survey and recommendations for future similar initiatives to quantify standardized baselines for dairy GHG mitigation programmes. Appendices present the data collection tool, the main descriptive statistics for the data collected and a comparison of the primary dataset with a dataset containing interpolated missing values, as well as other input data used.

## 2. Overview of the Smallholder Dairy Methodology requirements and baseline survey process

Figure 2 gives an overview of the methodological process for developing the standardized baseline and the corresponding sections in this report. The baseline survey was designed to provide the data needed to quantify GHG intensity of milk production per farm using the methodology set out in the Smallholder Dairy Methodology. The data collection tool used in the survey is shown in Appendix 1. The Smallholder Dairy Methodology requires that the baseline survey should be representative of smallholder dairy farms in the target region and cover production systems that contain at least 80% of smallholder dairy cows in the target region. For this, a sampling strategy is required (see Section 3).

**Figure 2. Overview of methodological process and corresponding sections in this report**



Once data has been collected and preliminary data analysis completed, the data is used to calculate parameters at three levels:

- **Individual animals:** data on several parameters (including milk yield) are used to estimate GHG emissions for each animal present on each farm during the survey, including cows as well as other cattle types, such as heifers, calves, bulls and replacement males;

- **Farm emissions:** GHG emissions and milk yield are calculated per farm, including GHG emissions from animals on-farm during the survey, emissions from animals that have exited the farm during the year prior to the survey, and emissions from animals kept off-farm for farms that do not maintain sufficient replacement animals to maintain the size of their dairy herd, but *excluding* surplus males that are not replacements for existing breeding males on the farm;
- **Stratum:** For the calculation of off-farm replacement animals and estimation of the standardized baseline, the methodology requires that some parameters are calculated as an average for each type of farm. In the Kenya case, farm types or strata are defined by feeding system, i.e. zero-grazing, mixed stall-fed + grazing (known as ‘semi-zero grazing’), and grazing only feeding systems.

The GHG emissions that must be quantified include emissions from several sources (Table 1). For all animals on-farm in the year prior to the baseline survey date, emissions from enteric fermentation and manure management (including on-farm manure management and deposit of urine and dung on pasture) should be quantified. Emissions occurring off-farm but attributable to on-farm dairy production include emissions embodied in fodder, feed and supplements consumed (including land use change), and emissions attributable to replacement animals currently off-farm.

**Table 1. GHG sinks and sources quantified in the Smallholder Dairy Methodology**

GHG sources	GHGs quantified
Enteric fermentation	CH <sub>4</sub>
Manure management	CH <sub>4</sub> , N <sub>2</sub> O
Fodder and feed production and fertilizer use	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O
Feed processing and distribution	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O
Land use change	CO <sub>2</sub> , CH <sub>4</sub>
Fertilizer manufacture & distribution	CO <sub>2</sub> , N <sub>2</sub> O
Supplement manufacture and distribution	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O

Dairy systems produce both milk and meat, as well as other products, such as manure, and social and cultural services, such as savings and insurance and social prestige (Weiler et al. 2014). There are different ways to allocate the GHG emissions from dairy cattle production to these different outputs, such as physical allocation based on the protein in milk and meat produced, or economic allocation based on the financial or economic value of different products (IDF 2015). The Smallholder Dairy Methodology assumes that all dairy-related emissions arising on-farm are attributable to milk production, except for emissions from male cattle that are not essential for reproduction of the herd. For example, oxen and male calves that are surplus above the numbers required to replace existing bulls are not included in the estimate of total emissions per farm. The final analysis requires an estimate per farm of GHG emissions (kgCO<sub>2</sub>e) per unit of fat and protein corrected milk (kg FPCM). Regression analysis is then used to establish the relationship between GHG emission intensity (kgCO<sub>2</sub>e kgFPCM<sup>-1</sup>) and FPCM yield across all households in the baseline survey.

In the case presented in this report, the model for calculating GHG emissions was constructed in MS Excel. Other analysis to establish intermediate variables for input into the GHG model was conducted using either MS Excel or SPSS Statistics.

## 3. Sampling and data collection

### 3.1. Methodology requirements

The Smallholder Dairy Methodology states that the standardized baseline methodology is applicable under the following conditions:

“(a) In regions where dairy production already occurs on a scale sufficient that a sample survey can quantify baseline management practices to a precision level of 90%±10%;

(b) The survey to determine the standardized baseline covers the different types of dairy farm operations that raise at least 80% of dairy animals in the project region (excluding dairy operations that are not small-scale as defined in footnote 1 above)” (Gold Standard and FAO 2016, p.13).

Applicability condition (a) is intended to ensure that the population of dairy farms is sufficient to enable a representative sample to be taken. The term “baseline management practices” is not well defined. Life Cycle Assessment (LCA) of dairy production in smallholder dairy systems generally finds that enteric methane production is the largest single source of GHG emissions, accounting for 68% to 88% of total CO<sub>2</sub>e emissions (Weiler et al. 2014, FAO and NZAGRC 2017). Gross energy intake is a key determinant of both enteric fermentation and manure management emissions. In smallholder dairy systems such as in Kenya, gross energy intake is largely driven by animal live weight (LW) and the energy digestibility of feed, which co-determine dry matter intake (DMI). Milk yields may also be a major driver of gross energy intake if it is sufficiently high such that net energy for lactation is a significant proportion of total net energy requirements.

The Smallholder Dairy Methodology refers to guidance on sampling from the CDM.<sup>1</sup> That guidance clarifies that where there are multiple parameters to estimate through sampling, the sample size shall be given by the largest sample size of the different parameters required to achieve a precision level of 90%±10%. Appendix 3 provides analysis of the precision achievable for key driving variables with different sample sizes using the survey data from Kenya.

Applicability condition (b) implies that only smallholder dairy farms need be sampled, since the Smallholder Dairy Methodology is not applicable to large-scale, industrial dairy farming operations. Note that if sampling follows this requirement, then the resulting data may not be fully representative of all dairy farms or dairy cows in the target region. This may limit the application of the data to other purposes, e.g. for use in national GHG inventories.

### 3.2. Sampling strategy

Several sources give general guidance on sampling for rural household surveys (e.g. UN DESA 2005). Considering transport and other survey costs, multistage cluster sampling may be a cost-effective sampling method. With multistage cluster sampling, enumeration areas (e.g. wards, villages) are selected randomly from within the target region, and clusters of households (e.g. households in the same village) are selected in each enumeration area. The multistage sampling procedure employed to select representative locations (enumeration areas) and households in the pilot baseline survey in Kenya is elaborated below.

**Stage 1: Identification of the target population:** For the pilot baseline survey, the target population was identified as households with dairy cattle in the intensive production region of Kenya. The intensive production region had

<sup>1</sup> [https://cdm.unfccc.int/Reference/Standards/meth/meth\\_stan05.pdf](https://cdm.unfccc.int/Reference/Standards/meth/meth_stan05.pdf)

been identified by a previous study of dairy production in Kenya by FAO (FAO and NZAGRC 2017). The counties in this region are: Embu, Kiambu, Kirinyaga, Meru, Murang'a, Nakuru, Nyandarua and Nyeri.<sup>2</sup>

**Stage 2: Sampling of enumeration areas:** Considering the resources available for the pilot baseline survey, within each county it was planned to sample households clustered in 41 enumeration areas, with 10 households per cluster. Since there were no prior lists of households with dairy cattle, enumeration areas were chosen by randomly selecting locations within each county using a script to perform random selection of locations in GIS after blocking out forest and urban areas. The selected points were moved to the nearest village, school, crossroads or other identified location. Twelve points were selected in each county, with two points being used as replacement enumeration areas in case any of the selected enumeration areas had insufficient numbers of dairy producing households. Prior to the survey, the location of each site and the presence of dairy production in the nearest village was verified, and contacts with the resident administrative officials were made.

**Stage 3: Random sampling of households:** Since there are no prior lists of households with dairy cattle in each village or enumeration area, a transect sampling method was used (Staal et al. 2002). Discussions with the local administration were held to produce a hand-drawn map of the village and identify key landmarks (e.g. river, school, church etc.) on each side of the village. Pairs of landmarks were selected and straight lines (transects) were drawn between them. One transect was chosen at random, and the enumeration team walked along the transect sampling every fifth household along the transect, until 10 households with dairy cows had been interviewed. If a household was selected that does not have dairy cows, then the enumeration team proceeded to the next sampled household (i.e. 5 households later). If a transect was completed and still 10 households had not been interviewed, another transect was randomly selected and household sampling repeated in the same manner. In the pilot baseline survey, 429 households were sampled at locations shown in Table 2.

<sup>2</sup> This grouping of counties differs slightly from the counties identified as having 'intensive production systems' in Kenya's Tier 2 dairy cattle GHG inventory (State Department of Livestock 2019).



**Table 2. Countries and constituencies sampled in the pilot baseline survey in Kenya**

County	Constituency	Number of Household surveyed
Embu	Manyatta	13
	Mbeere South	10
	Runyenjes	10
Kiambu	Gatundu North	12
	Gatundu South	10
	Kiambaa	11
	Kikuyu	20
	Lari	10
	Ruiru	8
Kirinyaga	Gichugu	22
Meru	Buuri	10
	Igembe South	18
	Imenti South	9
	Tigania East	10
Muranga	Gatanga	10
	Kandara	11
	Kangema	8
	Kigumo	17
	Kiharu	10
	Maragwa	8
Nakuru	Bahati	10
	Gilgil	21
	Kuresoi North	9
	Kuresoi South	11
	Molo	19
	Nakuru Town West	10
Nyandarua	Kinangop	36
	Kipipiri	17
	Ol Kalau	19
Nyeri	Kieni	10
	Mathira	10
	Mukurweini	10
	Nyeri	10

### **3.3. Data collection**

#### **3.3.1. Data collection tool**

Appendix 1 shows the data collection tool used in the pilot baseline survey. Appendix 2 summarizes which of the parameters required by the Smallholder Dairy Methodology are derived from which sections of the survey tool.

In particular, it is worth noting that the definition of animal sub-categories used in the survey tool differs from more common categorizations used in Kenya. The survey tool codings give 13 animal sub-categories, which is more than is usually used in household surveys of dairy production. The reasons are:

- (a) sub-dividing adult males in bulls and oxen is used to select the appropriate value for the coefficient for growth (C) in the IPCC model, which varies between castrated and intact males;
- (b) subdividing cows into lactating, dry and lactating in-calf cows is used together with other information on milk production and calving interval to ensure a more accurate estimate of the proportion of cows that were pregnant in the year;
- (c) subdividing heifers into those that are and are not in-calf is useful to correctly apply the coefficient for pregnancy ( $C_p$ ) to heifers that have not yet calved.

#### **3.3.2. Enumerator training**

A team of enumerators was formed that consisted of professionals and graduate students with animal or veterinary science or social science background. All had previous experience of conducting household surveys. Three survey team leaders with prior experience of managing survey teams in the field and quality control were also in the team. A two-day training course was provided, with the first day covering every detail of the sampling procedure and survey tool, and the second day involving trial data collection with dairy farming households.

#### **3.3.3. Selection of respondents**

Because the survey requires in-depth familiarity with the dairy cattle raising practices of the household, the questionnaire must be answered by an adult household member with some responsibility for dairy cattle keeping. The questions on the introductory page of the survey tool (Appendix 1) aim to ensure that eligible household members were identified. The respondent may be the household head, spouse or another adult household member. Hired workers may only be the main respondent if the household head or spouse has agreed. If the household head is not involved in dairy cattle raising, enumerators were instructed to identify another eligible household member with more specific knowledge of household dairy management practices. The respondent eventually selected responded to the questionnaire.

## 4. Preliminary data analysis

### 4.1. General procedures

The raw data was entered into SPSS. Data cleaning involved checks for transcription errors (e.g. values that were not present in the item codings, implausible parameter values), and cross-checks of the categorization of each animal by sub-category against reported age, live weight (LW), calving and lactation history. In particular, the age of animals was used to confirm that the recorded age of each animal is within the age range for the definition of each animal sub-category, and to check that the pregnancy, birth or lactation status of each type of cow corresponds to the definition for each sub-category of cow. Outlier parameter values were cross-checked against the original survey forms, and in a small number of cases the respondent was re-contacted in order to cross-check reported values or replace missing values.

### 4.2. Survey-specific procedures

The definition of dairy farm strata used in analysis of the baseline survey data was determined ex-post on the basis of data collected by the survey tool on feeding management for productive females in each household (Table 4.2 in Appendix 1). Specific definitions used to allocate households to a feeding system were:

- Zero-grazing system: All productive females and replacement heifers are raised in zero-grazing systems in both dry and wet seasons. In some cases, male animals may be grazed, but since the intensiveness of production practices for females is expected to be the main determinant of milk production, the grazing system for females was used as the defining characteristic.
- Semi-zero grazing system: Some productive females or replacement heifers graze for some part of the year.
- Grazing system: All productive females and replacement heifers graze 100% of the time in both wet and dry seasons.

This information is given in responses to Question 4.2 in the survey tool (see Appendix 1), which was analysed prior to analysis of other survey data so that each farm was coded by feeding system prior to further analysis.

### 4.3. Dealing with missing values

There can be many reasons for incomplete data. Possible reasons include:

- Omissions when filling in questionnaire forms
- Lack of understanding or knowledge on the part of the respondent
- Requesting information in units or to a level of detail that farmers are unaccustomed to measuring
- Requesting information on too long a recall period
- Refusal to respond by the respondent, e.g. due to fatigue or other reasons.

Some of these reasons can be avoided, for example, by

- Testing the survey tool in a small-scale pilot
- Ensuring that survey enumerators are properly trained in both interviewing and documenting responses
- Ensuring that respondents have been regularly involved in farm dairy operations over the year prior to the survey
- Ensuring timely inspection of completed survey forms in the field, so that any omissions can be detected and follow-up interviews made
- Taking direct measurements, e.g. heart girth measurements, age estimation using dentition.

However, some of causes of missing data cannot be avoided. For example, resource limitations mean that it would not be possible to directly measure several parameters across a large number of households. In the pilot baseline survey, for example, enumerators were instructed to select one animal of each type present on the farm for heart girth measurement. This saved time but resulted in a large number of missing values for the live weight of animals that were not measured. Another example might be where cows are frequently purchased as mature animals, and the new owners may not know the age, parity, calving interval or dates of last calving for these animals.

Thirty-two cases (i.e. households) were deleted that had missing values for animal type, since it would not be plausible to impute values for other parameters if animal type is unknown, leaving a sample of 397 households for data analysis. Missing value analysis in SPSS Statistics was used to diagnose the extent, patterns and mechanisms of missing data in the primary dataset. First, the presence or absence of missing data were tabulated by each of the key parameters. This was done separately for cows (Table 3) and for other cattle types (Table 4), because variables such as age at first calving or milk yield are by definition 'missing' for other animal types. For example, results for cows (Table 3) show that among 12 variables, there were no missing values for feeding system type, animal type or feed digestibility, and few missing values for breed or body condition, but 14-51% of cases had missing values for other variables. Overall, for cows 90% of cases had at least one missing value, with 28% of all values missing. For other cattle types, age and/or live weight (LW) were missing in 32%-43% of cases, and 53% of cases had at least one missing value.

**Table 3. Missing values in the primary dataset for cows**

Variable	Number present	Number missing	% missing
Feeding system	726	0	0%
Digestibility of feed	726	0	0%
Animal type	726	0	0%
Breed	719	7	1%
Body condition	670	56	7.7%
Parity	624	102	14%
Peak milk yield	622	104	14.3%
Minimum milk yield	620	106	14.6%
Live weight	386	340	46.8%
Age	374	352	48.5%
Days since calving	369	357	49.2%
Calving interval	362	364	50.1%
Age at first calving	357	369	50.8%

**Table 4. Missing values in the primary dataset for other cattle types**

Variable	Number present	Number missing	% missing
Feeding system	646	0	0%
Digestibility of feed	646	0	0%
Animal type	646	0	0%
Breed	636	10	1.5%
Body condition	604	42	6.5%
Age	438	208	32%
Live weight	368	278	43%

In general, missing values were frequent for LW and age for all animal types, and for days since calving, calving interval and age at first calving for cows. Concentration of missing values in these variables might suggest a non-random pattern of missingness. To determine the type of missingness, the pattern of missingness was visualized (Figures A5.1 and A5.2 in Appendix 5). The data show both instances of random distribution of missing values (indicated by isolated red cells) and monotone missingness, as indicated by patches of missing values in the lower right hand corner of each figure. Chi-squared tests on crosstabulations between missingness patterns was performed (Appendix 5, Tables A5.2 and A5.4). For cows, the results suggest that other variables are more likely to be missing when age, LW and age at first calving are missing. For other cattle types, breed and body condition were more likely to be missing for animals in semi-zero and grazing systems, and LW was more likely to be missing if data on body condition and age were also missing. This is as expected, since enumerators were instructed to measure heart girth of animals of known age only.

To test whether a case having a missing value was correlated with any other variable, for scale variables (e.g. age, live weight) the results of separate variance t-tests were inspected to compare the mean of each variable between cases with and without a missing value (Appendix 5, Tables A5.1 and A5.3). This suggested that for cows:

- when data on age is missing, the number of lactation days in the year is higher;
- when age at first calving (AFC) is missing, peak milk yield is estimated to be lower;
- when parity is missing the calving interval is estimated to be lower;
- when the calving interval is lower, parity and peak milk yield are estimated to be lower;
- when lactation days in the year is missing, parity is estimated to be lower

In addition, Little's missing completely at random (MCAR) test was conducted to test whether data were MCAR or not. The results of Little's MCAR test for cows were Chi-Square = 511.813, DF = 316, Sig. <0.01 and for other cattle types were Chi-Square = 25.470, DF = 5, Sig. <0.01, indicating that data were not missing completely at random. Therefore, we assumed that the data is missing at random (MAR). This type of missing data is suitable for multiple imputation.

The imputation method chosen was predictive mean matching (PMM), where missing values are imputed using the observed values with the closest predictive mean from a linear regression model. PMM was chosen because it is suitable for constrained variables (i.e. variables with only positive values or values below a given maximum), for discrete values (e.g. variables like parity that have only discrete values), and for variables that are not normally distributed (e.g. live weight, milk yield in the Kenya case). Variables were transformed to normal distributions before implementing multiple imputation. Since some parameter values are more or less likely if other missing parameter values have already been imputed (e.g. a more reliable estimate of parity can be obtained if age is already known), for cows, the order of imputation of missing variables was:

- Breed, age, body condition, LW, AFC, calving interval, parity, peak milk yield, minimum milk yield, days in lactation.

For other cattle types, the order of imputation of missing variables was:

- Breed, age, body condition, LW.

Given the rates of missingness, for both cows and other cattle types, 50 imputations were made (Graham et al. 2007), with the final pooled value for each missing data taking the mean of all 50 imputations.

A comparison between the primary survey data and the dataset after imputation using PMM is given in Appendix 5 Tables A5.5 and A5.6. The comparison shows that for all parameters, there were slight differences in the mean values and standard deviation of the primary and imputed datasets. As is common with multiple imputation methods, for all variables the standard deviation of the imputed dataset was smaller than for the primary dataset.

## 5. Calculation of GHG emissions

Preliminary data analysis described in the previous section created a full dataset of the parameters required for estimating GHG emissions from each animal and thus each farm surveyed. This section explains the methods used to transform the raw data into estimates of GHG emissions and milk yields per animal and per farm.

### 5.1. Quantification of individual animal GHG emissions and milk yield

GHG emissions attributable to each animal present on the farm during the year prior to the survey include:

- (1) Methane emissions from enteric fermentation
- (2) Methane emissions from manure management
- (3) Nitrous oxide emissions from manure management and dung and urine deposited on pasture
- (4) Emissions embodied in feed consumed on farm.

Estimates from (1)-(4) are then used to estimate:

- (5) Emissions from animals that were present on the farm for only part of the year, and
- (6) Emissions from replacement animals that are not kept on the farm.

#### 5.1.1. Enteric fermentation emissions

The method required by the Smallholder Dairy Methodology for quantification of enteric fermentation emissions is the IPCC Tier 2 approach. The specific IPCC equations are not presented here, but can be found in the IPCC Guidelines (IPCC 2006). Table 5 shows the variables for which data is required. The baseline survey data indicated that only 2 out of 1400 dairy cattle surveyed did any work during the year, so net energy for work was not calculated.<sup>3</sup> Each of the following sub-sections describes how the parameters required for estimation of enteric fermentation emissions using the IPCC Tier 2 model can be obtained from analysis of the baseline survey data. Note that because net energy for maintenance is an input into the estimation of net energy for activity and net energy for pregnancy, it was calculated first.

<sup>3</sup> If any type of dairy cattle do significant amounts of work, the IPCC guidelines should be followed to estimate net energy for work.

**Table 5. Variables required for estimation of enteric fermentation emissions per animal per year**

	Parameter	Description, units
A	Live weight (LW)	Live weight per animal, kg
B	Mature weight (MW)	Weight of mature animals, kg
E	Weight gain	Average daily weight gain, kg day <sup>-1</sup>
D	Milk yield	Annual average daily milk yield, kg day <sup>-1</sup>
E	C <sub>f</sub> <sub>i</sub>	Coefficient for maintenance, dimensionless
F	C <sub>p</sub>	Coefficient for pregnancy, dimensionless
G	C <sub>a</sub>	Coefficient for activity, dimensionless
H	C	Coefficient for growth, dimensionless
I	%DE	Digestible energy as a % of gross energy, %
J	GE	Gross energy per animal per day, MJ head <sup>-1</sup> day <sup>-1</sup>
K	Y <sub>m</sub>	Methane conversion factor, %
L	EF	Enteric fermentation emission factor, kg CH <sub>4</sub> head <sup>-1</sup> year <sup>-1</sup>

Note: For further definitions and units, see IPCC (2006).

#### (A) Live weight

**Data input:** The baseline survey tool instructs enumerators to collect heart girth (HG) measurements on each farm, selecting one animal of each type of known age and noting its body condition. The reason for noting body condition is that NRC (1996) defines mature weight (MW) as the shrunk weight of cows with a parity of 4 or more and *in moderate body condition*.

**Data analysis:** The aim of analysis is to convert HG measurements into estimates of live weight. This was done for all available observations prior to imputation of missing data. The survey data contains HG measurements of all animal types, from calves through to mature animals. Research in East Africa (Goopy et al. 2018a) suggests that over a large range, the best estimate of LW can be obtained using the equation:

$$LW = (0.01543 + (0.0492 * HG))^{-0.3595} \quad (\text{Eq. 1})$$

For all HG measurements (including animals in poor body condition), HG measurements were converted to an estimate of LW in kg using Equation 1.

Although data from Kenya shows that LW can vary in different seasons of the year (Goopy et al. 2018b, Ndung'u et al. 2019), IPCC (2006) suggests that “[r]educed intakes and emissions associated with weight loss are largely balanced by increased intakes and emissions during the periods of gain in body weight.” Therefore, the LW estimated on the basis of heart girth measurements was taken to represent the annual average LW.

#### (B) Mature weight

**Data input:** Analysis uses the estimated live weight calculated in (A) above, together with data from the baseline survey on age to estimate mature weight (MW).



**Data analysis:** The aim of analysis is to estimate the MW for male and female cattle in each stratum (e.g. feeding system). For females, MW is defined as the shrunken body weight of cows after their 4<sup>th</sup> parity in moderate body condition, and shrunken body weight is estimated as live weight multiplied by 0.96 (NRC 1996). Where there is no statistically significant difference between strata, or where the sample size is too small (e.g. for castrated oxen, which were uncommon on dairy farms in the baseline survey) a single value was used in the GHG calculations for all strata. For example, given very small samples of bulls (n=47) and oxen (n=5), after excluding males in poor body condition, the top quartile of LW was used to estimate MW. For cows, there were no statistically significant differences between mean live weights of mature cows in different feeding systems, so a single estimate of MW was used.

### (C) Daily weight gain

**Data input:** Analysis used the estimated LW calculated in (A) above, and data from the baseline survey on animal type and age to estimate daily weight gain (WG).

**Data analysis:** The aim of analysis is to estimate daily weight gain for each type of growing animal (i.e. male and female calves, heifers and growing males). Following IPCC (2006), we assume that weight gain for adult cows and males is equal to zero. Daily weight gain is used to estimate net energy for growth for each animal type.

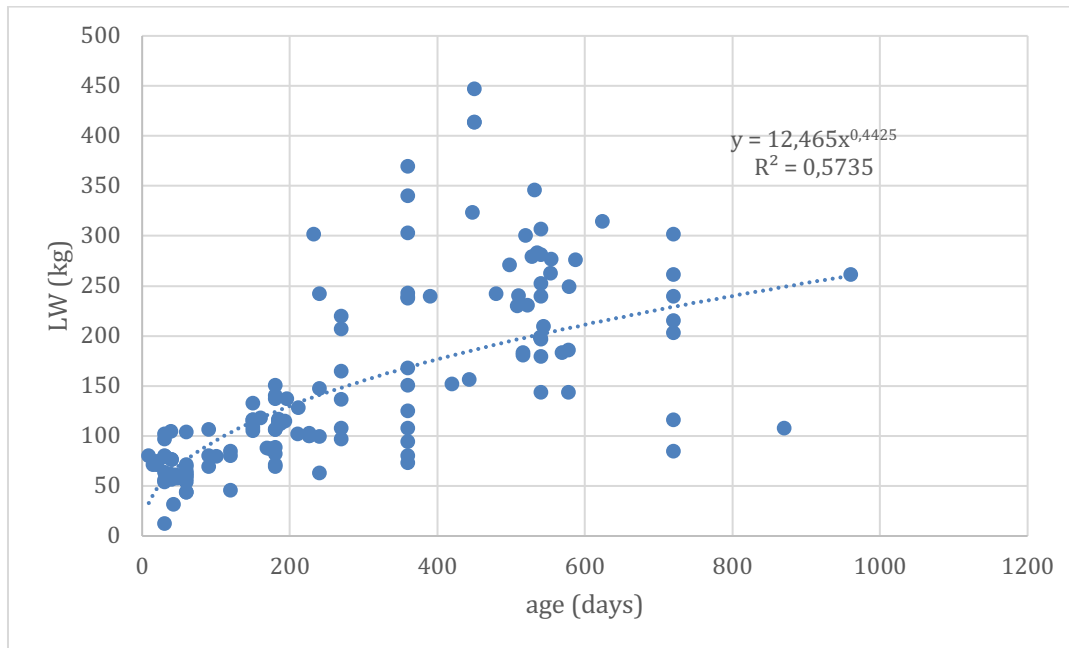
Calf daily weight gain is expected to be higher at younger age, gradually decreasing as age increases, and many calves in the survey were less than 6 months old. So estimating daily weight gain by dividing weight gain since birth by the number of days since birth for each animal would overestimate annual average daily weight gain for calves that had been alive for less than a year. Therefore, annual average daily weight gain was estimated for each sub-category of growing animal in each stratum.

Using data on LW calculated in (A) above for growing cattle types (i.e. male and female calves, heifers and growing males), the dataset was divided by stratum (i.e. feeding system). Survey data on age in months was converted to age in days. A best-fit regression equation was established between age in days and LW for male and female calves separately. The resulting equations were used to estimate LW for the typical animal of each sex for each age group of growing animal. From the estimate of LW at each age, average daily weight gain (i.e.  $\Delta LW$ ) during the period representing the age range of each animal type was estimated.

Take the example of young male animal types. Sample sizes for male calves and growing males in each stratum were small. Preliminary inspection of the distributions of LW and age for each stratum revealed no obvious differences. Therefore, data for male calves and growing males were pooled to include all feeding systems. Curve fitting was then used to establish a relationship between LW and age (see Figure 3). This relationship was then used to predict LW at each week from birth until 3 years old, and thus to calculate  $\Delta LW$  and  $\Delta LW$  per day during each week. As a result, male calves are predicted to gain 0.34 kg per day in their first year, and growing males to gain an average of 0.15 kg per day in years two and three, while female calves gain 0.42 kg per day in the first year and heifers gain an average of 0.26 kg per day in the second and third years.

For pre-weaning calves, weight gain can also be used to estimate milk consumption by calves, since this may not be included in farmer-reported estimates of milk yield. The methods for estimating milk consumption from calf weight gain are described in NRC (2001). However, for Kenya, literature reports that bucket feeding is common (Gitau et al. 1994, Nafula 2013, Lukuyu et al. 2011) but the baseline survey did not collect sufficiently detailed data on calf management to discriminate whether farmer milk yield estimates included calf suckling. Therefore, calf milk consumption was not calculated separately from farmer reported milk yield. This highlights an option for improvement in the survey tool in Appendix 1.

**Figure 3. Relationship between LW (kg) and age (days) for male calves and growing males**



(D) Annual average fat and protein corrected milk yield

**Data input:** The baseline survey method for estimating average daily milk yield during the lactation is to collect farmer reported values of the peak and minimum milk yield in the lactation, and estimate average daily milk yield as the average of the peak and minimum milk yield. Data on the survey date and the date of last calving are used to estimate the number of days in the current lactation. This is then transformed to an estimate of average annual daily fat and protein corrected milk yield.

**Data analysis:** Analysis was completed in several steps:

First, farmer-reported data on peak and minimum daily milk yield in litres were converted to kg using a standard conversion of 1.031 kg per liter. Second, since milk yield decreases as duration of lactation increases, farmer-reported milk yield will underestimate minimum milk yield for cows that have not finished their current lactation. Standard lactation curves have not been established for cows managed under smallholder farming conditions, so best-fit curve fitting was used to estimate a standard curve from the survey data.

To estimate minimum milk yield for a full lactation, the data on peak and minimum milk yield for the sub-sample of cows that were reported to have dried (n=28) and the sub-sample of cows that had dried or whose lactation duration was greater than 305 days (n=93) were used. Linear regression was used to test the association of feeding system, breed, parity, lactation duration, peak yield and calving interval with minimum yield. Results indicated that for dried cows, only peak yield was significant (coefficient 0.493, adj.  $r^2=0.43$ ), while for 305-day lactation cows, both peak yield and parity were significantly associated with minimum yield (peak yield coefficient 0.44, parity coefficient - 0.36, adj.  $r^2=0.49$ ). This implies that for a 1 kg increase in peak yield, minimum yield in the lactation would be 0.44 kg higher, while each successive parity reduces milk yield by about 0.36 kg. Using this result, average daily milk yield during a lactation was calculated as the average of peak and predicted minimum yield (Equation 2), unless

farmer-reported minimum yields were lower than the predicted value, in which case the farmer-reported value was used:

$$(\text{Peak yield} + (-0.36 \cdot \text{Parity} + 0.44 \cdot \text{Peak yield})) / 2 \quad (\text{Eq.2})$$

Third, the IPCC model works on the basis of calculating the annual average daily milk yield, but the preceding steps have only produced an estimate of average milk yield per day during lactation. Therefore, the average daily milk yield during lactation should be converted to an annual average daily milk yield by adjusting for the period of the year during which each cow was lactating. In order to do this, the number of days in lactation during the year prior to the survey was estimated. Since many cows were still part-way through their current lactation on the survey date, days in lactation during the year prior to the survey should include days in the current lactation and any days in the prior lactation if that also occurred during the year prior to the survey date. For this, the following data is needed:

- date of the survey
- date of last calving
- days dry before last calving and
- date dried (where relevant)

Table 6 summarizes the different methods used to calculate days in lactation during the year prior to the survey for cows of different lactation status at the time of the survey.

**Table 6. Methods for estimating days lactating**

Cow status at time of survey	Calculation method for number of days lactating in year prior to survey*
Currently lactating and parity >1	[Date of survey - date of last calving] + [(date of last calving - days dry before last calving - 365)]
Currently lactating and parity =1	[Date of survey - date of last calving]
Currently dry	[Date dried - date of last calving] + [(date of last calving - days dry before last calving - 365)]

\* In all cases, no day prior to 365 days before the survey date is counted.

Using the number of days in lactation in the year prior to the survey, the annual average daily milk yield was calculated as:

$$(\text{Annual daily milk yield in lactation} \cdot \text{number of days in lactation}) / 365 \quad (\text{Eq. 3}).$$

Fourth, annual average daily milk yield is converted to fat and protein corrected milk (FPCM) using the equation:

$$\text{Annual average daily FPCM} = \text{annual average daily milk} \cdot (0.337 + 0.116 \cdot \text{Fat} + 0.06 \cdot \text{Protein}) \quad (\text{Eq. 4})$$

Default values were used for fat content of milk (4%) and protein content of milk (3.5%) (IPCC 2006).

These results are used in subsequent calculations:

- Annual average FPCM yield per day per cow is used together with estimates of proportion of the year that the cow is present on the farm to estimate milk production by lactating animals that left the farm before the survey date;

- Annual average FPCM yield per day per cow is multiplied by the proportion of the year that each animal was present on the farm to estimate annual FPCM per animal;
- The sum of annual FPCM per animal for all animals on the same farm is calculated to estimate annual FPCM per farm.

#### (E) Coefficient for maintenance ( $C_f$ )

**Data input:** IPCC (2006) gives default values for the coefficient for maintenance ( $C_f$ ) for bulls, lactating cows and non-lactating cows. The IPCC default value for maintenance is 20% higher for lactating than for non-lactating cows. A value for  $C_f$  was calculated for lactating cows that is weighted by the proportion of the year lactating. The IPCC default value for bulls can be used as given in IPCC (2006). For other female cattle (e.g. heifers and female calves), the value for non-lactating cows (0.322) is used. For other male cattle (e.g. growing males and male calves), the value for intact bulls (0.370) is used.

**Data analysis:** For cows, days in lactation were estimated in (D) above using baseline survey data for each cow on the date of the survey, date of last calving and (where relevant) date dried. The IPCC default value for  $C_f$  for non-lactating cows is 0.322 and for lactating cows is 0.386. By weighting the coefficient by the proportion of the year spent lactating, the baseline survey derived a mean value for  $C_f$  of 0.372 (s.d. 0.010).

#### (F) Coefficient for pregnancy ( $C_p$ )

**Data input:** For productive cows, baseline data on date of last calving and calving interval is used to estimate the number of days in the year that each animal was pregnant. A coefficient for pregnancy ( $C_p$ ) is also applied to pregnant heifers.

**Data analysis:** The IPCC 2006 default value for  $C_p$  (i.e. 0.1) is an annualized estimate assuming a pregnancy of 281 days. It is normally applied together with an estimate of the % of cows giving birth in the year. However, the baseline survey collected finer resolution data on the number of days pregnant during the year prior to the survey, which may be considerably less than 281 days. Therefore, the aim of analysis is to adjust the coefficient for the number of days pregnant during the year.

The number of days pregnant during the year prior to the survey was calculated for each cow using the date of the survey, the date of last calving and assuming 281 days pregnancy:

Date pregnancy began = date of last calving – 281.

If (date pregnancy began – 1 year prior to the date of survey) > 0, then days pregnant in the year = (date of last calving - 1 year prior to the date of survey).

If (date pregnancy began – 1 year prior to the date of survey) < 0, then days pregnant in the year = 0.

$C_p$  is then calculated as (days pregnant in the year/281) \* 0.1.

The resulting mean value for  $C_p$  for cows was 0.06 (s.d. 0.03). For pregnant heifers, the IPCC default value was used (i.e., 0.1).

#### (G) Coefficient for activity ( $C_a$ )

**Data inputs:** The IPCC gives default values for the coefficient for activity ( $C_a$ ) based on feeding situation (i.e., stall feeding, grazing in confined pasture and extensive grazing). The IPCC default values for  $C_a$  are 0 for no grazing, 0.17 for confined grazing and 0.36 for extensive grazing. However, no quantitative definition of these feeding situations is given in the IPCC Guidelines.  $C_a$  is estimated following equations given in NRC (2001), which consider animal LW and distance travelled.

**Data analysis:** NRC (2001) suggests that there are two components to net energy for activity: a maintenance energy requirement for walking and a maintenance energy requirement for eating activity. NRC (2001) proposes a value of 0.0012 Mcal per kg body weight for energy associated with eating, and 0.00045 Mcal/kg BW per km distance of walking in flat areas. Mcal was converted to MJ by multiplying by 4.1868. Thus, assuming a cow body weight of 360 kg, the IPCC default of 0.17 for cattle grazing confined areas would apply to a cow walking 3.7 km per day and the value of 0.36 for extensive grazing would imply a distance on flat terrain of more than 12 km per day.

The baseline survey data was analysed as follows:

$$\text{Annual average km walked per day} = (\text{km in wet season} * (\text{months of wet season}/12)) + (\text{km in dry season} * (\text{months in dry season}/12)) \quad (\text{Eq. 5})$$

If the proportion of DMI per day obtained from grazing >0, then:

$$C_a = ((0.00045 * LW * \text{annual average km per day}) + (0.0012 * LW) * 4.1868) / NE_m \quad (\text{Eq. 6})$$

where  $NE_m$  is net energy for maintenance, calculated using IPCC (2006) Equation 10.3.

If the proportion of DMI per day obtained from grazing = 0, then:

$$C_a = ((0.00045 * LW * \text{annual average km per day}) * 4.1868) / NE_m \quad (\text{Eq. 7})$$

The resulting average values for  $C_a$  were 0.001 in the zero-grazing system (due to a small number of males and replacement animals that were not 100% stall fed); 0.04 in the mixed system; and 0.06 in the grazing system. The baseline survey in Kenya was conducted in a relatively high population density area. More than 70% of sample households operated stall feeding systems for adult and replacement females. Even where there was a mixed stall + grazing system or a fully grazing system, distances estimated by farmers to and from the grazing site each day were small in both wet and dry seasons, with an annual average distance walked per day of 0.55 km in the mixed system and 1 km in the grazing system. Moreover, of those households in mixed or grazing systems, 55% reported tethering at least some animals when grazing. In the mixed and grazing systems, the average animal obtained only 30% and 34% of required DMI through grazing in each system, respectively. Taken together, this suggests that even in mixed and grazing systems in the survey area, most animals obtain a limited proportion of DMI from grazing, and a lower average value for  $C_a$  than the IPCC default values for grazing animals is justified.

#### (H) Coefficient for growth

**Data input:** Coefficients for growth used the IPCC default values, i.e. 0.8 for all females, 1.0 for castrated males and 1.2 for bulls. The default value for bulls was applied to growing males, and male calves as well as intact adult males.

## (I) Feed intake and feed energy digestibility

**Data input:** Baseline survey data on the mass of feed (including roughage, concentrates and organic or inorganic supplements fed) fed to each animal type in each farm is the main input data. In addition, analysis requires the following inputs:

- Feed unit conversions to kg: Farmers use a variety of units to transport roughage harvest and to feed animals (e.g. *debe*, wheelbarrow loads, *kasuku* cans etc). Conversions to kg were obtained from the literature and from expert judgement.
- Dry matter conversion factors: Feeds reported in the baseline survey include fresh weight and dried fodders, both of which contain moisture. Weights must be converted to dry matter weights.
- Feed digestibility: Feed digestibility values were not measured in the survey, but were derived from the literature for Kenya, East Africa (where Kenya data are unavailable) or from Feedipedia (where East Africa data are unavailable). At the same time, feed crude protein content (CP%) estimates were obtained for use in the N<sub>2</sub>O manure management emission estimates.

Dry matter content and feed digestibility values were obtained from scientific publications based on studies conducted in Kenya, the ILRI feed database,<sup>4</sup> and from an East Africa regional feed table (Laswai et al. 2013) and are presented in Appendix 6 Table A6.1.

**Data analysis:** The aim of analysis is to estimate the average feed energy digestibility of the total feed basket for each animal in the baseline survey. For analysis, the following steps were followed:

- (1) Convert baseline survey feed units into kg;
- (2) Convert kg fresh and dry feed into kg DM;
- (3) Using baseline survey data on the types of animals fed each type of feed in the wet and dry seasons, estimate the total volume of each type of feed available to each animal on each farm in each season. If the survey indicated that the type of feed was fed to all animal types, then the total available feed was divided by the number of animals present on the farm; if the survey indicated that the feed was fed to specific animal types, the total volume available was divided by the number of animals of that type present on the farm.
- (4) Estimate the total amount of each type of feed available per animal per day in each season and then estimate the average annual daily total amount available per animal weighted by the lengths of the wet and dry seasons.
- (5) Using data on LW of each animal and digestibility of available feed per animal, apply the appropriate IPCC equations to estimate DMI requirements for each animal (IPCC 2006 Vol. 4 Ch. 10 Equations 10.17-20.18. For growing cattle, a NE<sub>ma</sub> value of 5.0 was assumed).
- (6) Compare the estimated DMI requirements with the estimated DM feed available (DMA). If necessary, adjustments are made as follows:
  - a. If estimated DMA is > DMI, then it is assumed that intake from grazing equals zero. If the survey data reports that grazing animals are tethered, this is a reasonable assumption. Check that feed and supplement feeding rates and roughage:concentrate ratios are reasonable. Taking feed and supplement volumes as fixed, adjust the volume of roughage fed so that the proportion of each roughage type in the total ration is the same as reported by farmers, and the total sum of roughage, concentrate and supplement equals estimated DMI requirements.

<sup>4</sup> <https://feedsdatabase.ilri.org/>

- b. If estimated DMA is < DMI, then assume that the remaining intake requirement is met through grazing. Cross-check this assumption against the baseline survey data on the proportion of time spent grazing in each season. Where this assumption is inappropriate (e.g. for animals kept under zero-grazing), adjust the total volume of roughage available in proportion to their availability as reported by farmers such that DMA=DMI.
- (7) Once the composition of the total ration has been estimated, multiply the dry matter weight of each type of feed consumed by its energy digestibility and calculate the weighted average feed digestibility of the total ration consumed.

The resulting estimated diet composition and average annual feed digestibility is shown in Appendix 6 (Tables A6.2 – A6.5). Although this method of estimating feed intake has many shortcomings, because the volumes of each type of feed consumed will also be used to estimate the emissions from feed production, it is important that the estimated volumes are biologically feasible.

#### (J) Calculate gross energy

**Data input:** The parameter values calculated in the preceding subsections are the inputs into the IPCC equations for estimating gross energy (GE) intake (IPCC 2006, Eq. 10.14-10.16).

**Data analysis:** The aim of analysis is to estimate GE for each animal present on each farm. The parameter and coefficient values previously calculated are used together with the IPCC equations to estimate GE.

#### (K) Methane conversion factor

**Data input:** The IPCC default value for the methane conversion factor ( $Y_m$ ) of 6.5% was used for all cattle types.

#### (L) Calculate enteric fermentation emission factors

**Data input:** Estimated GE and data on entry and exit of animals from each farm are used together with the IPCC equations to estimate an annualized emission factor for each animal.

**Data analysis:** IPCC (2006) Equation 10.21 provides the equation to calculate an annual emission factor per animal:

$$EF = \left[ \frac{GE \times \left( \frac{Y_m}{100} \right) \times 365}{55.65} \right] \quad (\text{Eq. 8})$$

For animals that were present on the farm throughout the year, this equation can be directly used. The estimated enteric fermentation emission factors assuming animals are present on the farm for 365 days of the year prior to the survey are shown in Appendix 6 (Table A6.6). Where data on entry to the herd indicate that an animal was born, purchased or otherwise entered the herd during the year prior to the survey, calculate the proportion of the year for which each animal was present, and multiply the estimated emission factor by that proportion.

### 5.1.2. Methane emissions from manure management

The method used to estimate methane emissions from manure management is the IPCC Tier 2 method. The aim of analysis is to estimate an emission factor ( $\text{kg CH}_4 \text{ head}^{-1} \text{ year}^{-1}$ ) for each animal in the baseline survey and then to sum manure management methane emissions per farm. Table 7 shows the parameters required.

**Table 7. Parameters in the IPCC manure management methane emission model**

	Parameter	Description, units
M	Volatile solids (VS)	Volatile solids excreted per animal per day, $\text{kg dry matter head}^{-1} \text{ day}^{-1}$
N	Maximum methane producing capacity ( $B_0$ )	Maximum methane producing potential of manure, $\text{m}^3 \text{ CH}_4 \text{ kg}^{-1}$ of VS excreted
O	$\text{MCF}_{(S,k)}$	Methane conversion factor for each manure management system (S) in each climate region (k), %
P	Manure management system (MMS)	Fraction of manure managed in each manure management system, dimensionless
Q	EF	Manure management emission factor, $\text{kg CH}_4 \text{ head}^{-1} \text{ day}^{-1}$

Note: For further definitions and units, see IPCC (2006).

#### (M) Volatile solids

**Data input:** Sections (I) and (J) estimated DE% and GE for each animal. These are used together with IPCC default values for urinary energy as a fraction of GE (0.04) and ash content of manure (0.08) to calculate VS using IPCC (2006) Equation 10.24.

**Data analysis:** Apply the IPCC equations using the data inputs above.

#### (N) Methane production potential

**Data input:** Since this is rarely measured, literature values can be used.

**Data analysis:** IPCC (2006) Tables 10A-4 and 10A-5 give default values used for dairy cattle and other cattle in the IPCC guidelines. The default values for Africa are 0.13 and 0.1 respectively. However, these refer to animals with daily VS excretion of 1.5-1.9 kg, and DE% values of 55-60%. The value for VS in particular is much lower than the estimates produced in this survey. The source of the IPCC defaults is Safley (1992). There, on the basis of very limited data, the authors cited  $B_0$  values from the US of  $0.1 \text{ m}^3 \text{ CH}_4$  per kg VS for dairy cattle fed on poor quality forage, 0.17 for dairy cattle fed on 72% roughage, and 0.24 for cattle fed on 58-68% silage. Safley (1992) identified no data for developing countries, so the IPCC defaults were estimated considering that developing country cattle consume about one third less gross energy than US cattle, and a value of 0.1 was chosen for non-dairy cattle in developing countries, with the value for dairy cattle about 30% higher, following US data.

In the Kenya case, digestible energy intake for mature cows averaged about one third higher than the figures cited in Safley (1992), so the value from US research on cattle with 72% roughage (i.e. 0.17) was chosen for mature cows, and a value of 0.135 (as the mid-point between 0.1 and 0.17) used for other cattle types.



(O) Methane conversion factors (MCF)

**Data input:** IPCC gives MCFs for different manure management systems. The default values were used together with data on manure management systems from the baseline survey and estimated annual average temperatures.

**Data analysis:** The MCF for some management systems depends on annual average temperatures. Annual average temperatures for each county included in the survey were obtained from the 1991-2015 time series at the Climate Change Knowledge Portal.<sup>5</sup> Estimated average temperatures for each county were applied to identify the appropriate MCF for liquid/slurry management in the baseline survey. For other management systems, the default MFCs for the temperate climate region were used.

(P) Manure management systems

**Data input:** The baseline survey collected data on the proportion of manure managed in different systems.

**Data analysis:** The farmer reported data referred only to the proportion of manure on the farm managed in different systems, but did not consider manure deposited on pasture. The survey data was reviewed to ensure that the proportion of time spent on pasture was reflected in the estimate of proportion of manure deposited on pasture, considering also that in many cases, the location of the pasture was less than 200 m from the homestead (i.e. it is still feasible for households to collect manure deposited on pasture and manage it in other ways).

(Q) Estimate manure management methane emission factors

Using the values estimated in (M) to (P), together with IPCC equation 10.23, emission factors were calculated. These emission factors are shown in Appendix 6 (Table A6.7).

### 5.1.3. Nitrous oxide emissions from manure management and dung and urine deposited on pasture

The IPCC Tier 2 methods identify three sources of N<sub>2</sub>O emission from manure management:

- Direct N<sub>2</sub>O emissions
- Indirect emissions from volatilization
- Indirect emissions from nitrogen leaching (pasture management system only).

For most manure management systems, the relevant equations and emission factors are given in IPCC 2006 Vol 4 Ch 10, but for manure deposited on pasture, the equations and emission factors are given in Ch 11. Here, we estimated the direct and indirect nitrous oxide emissions from manure management and deposit of dung and urine on pasture as part of the same calculation process. Table 8 shows the parameters required.

<sup>5</sup> <https://climateknowledgeportal.worldbank.org/>

**Table 8. Parameters in the IPCC manure management N<sub>2</sub>O emission models**

	Parameter	Description, units
R	Nitrogen excretion (Nex)	Nitrogen excreted, kg head <sup>-1</sup> year <sup>-1</sup>
S	Gross energy (GE)	Gross energy (MJ head <sup>-1</sup> day <sup>-1</sup> )
T	CP%	Protein content of feed, %
U	MMS	Fraction of annual N excretion managed in different manure management systems, fraction
V	EF <sub>3</sub>	Direct N <sub>2</sub> O emission factor, kg N <sub>2</sub> O-N (kg N input) <sup>-1</sup>
W	Frac <sub>gasMS</sub>	Fraction of manure in each system that volatilizes as NH <sub>3</sub> and NO <sub>x</sub> , fraction
X	EF <sub>4</sub>	Emission factor for atmospheric deposition of N on water or soils, kg N-N <sub>2</sub> O (kg NH <sub>3</sub> -N + NO <sub>x</sub> -N volatilised) <sup>-1</sup>
Y	Frac <sub>leachMS</sub>	Fraction of N in manure in each management system lost due to run-off and leaching, fraction
Z	EF <sub>5</sub>	Emission factor for N <sub>2</sub> O emissions from runoff and leaching, kg N <sub>2</sub> O-N (kg N leached and runoff) <sup>-1</sup>

Note: For further definitions and units, see IPCC (2006).

**Data inputs:** In the IPCC approach, N excretion is estimated as the difference between N intake and N retention. N intake depends on the crude protein content of the diet (CP%). N retention depends on weight gain (for growing animal types) and milk yield and milk protein content (for cows).

Values for CP% were collected from the literature for Kenya, East Africa or globally from Feedipedia (see Appendix 6, Table A6.1). Milk yield used the milk yield estimated in (D) above, with a default value for milk protein content of 3.5% (IPCC 2006). Weight gain used the values estimated in (C) above. Data on the proportion of manure managed in different manure management systems was the same as in (P) above. To avoid double counting of N<sub>2</sub>O emissions from urine and dung deposited on pasture, these emissions were accounted for under manure management systems, and not as an emission embodied in pasture herbage consumed. The sources of other emission factors and variables used in the calculation of direct and indirect nitrous oxide emissions is shown in Table 9.

**Table 9. Parameters values used in calculating direct and indirect N<sub>2</sub>O emissions from manure management and deposit of dung and urine on pasture**

Manure management system	Parameter	Value used	Source
Daily spread	EF <sub>3</sub>	0	IPCC 2006 Table 10.21
Solid storage	EF <sub>3</sub>	0.005	IPCC 2006 Table 10.21
Dry lot	EF <sub>3</sub>	0.02	IPCC 2006 Table 10.21
Composted (static pile)	EF <sub>3</sub>	0.006	IPCC 2006 Table 10.21
Liquid slurry	EF <sub>3</sub>	0.005	IPCC 2006 Table 10.21
Biogas	EF <sub>3</sub>	0	IPCC 2006 Table 10.21
Pasture	EF <sub>3</sub>	0.02	IPCC 2006 Table 11.1
Daily spread	Fracgasm	7%	IPCC 2006 Table 10.22
Solid storage	Fracgasm	30%	IPCC 2006 Table 10.22
Dry lot	Fracgasm	20%	IPCC 2006 Table 10.22
Composted (static pile)	Fracgasm	30%	Value for deep bedding for 'other cattle' in IPCC 2006 Table 10.22
Liquid slurry	Fracgasm	40%	IPCC 2006 Table 10.22
Biogas	Fracgasm	0%	-
All MMS	Fracleach	0.3	IPCC 2006 Table 10.22
All MMS	EF <sub>4</sub>	0.01	IPCC 2006 Table 11.3
Pasture	EF <sub>5</sub>	0.0075	IPCC 2006 Table 11.3

#### 5.1.4. Emissions embodied in feed consumed on farm

The Smallholder Dairy Methodology uses an LCA approach in which emissions in the process of producing, transporting and processing fodder, feed and supplements are attributed to each animal on the farm. The methodology stipulates that feed emission factors should either come from peer reviewed publications, or publications of authoritative organizations, or be based on work conducted for the project proponents using LCA approaches consistent with ISO 14040 and ISO 14044. For estimation of emissions embodied in feed, the following emission sources were considered:

- N<sub>2</sub>O emissions from fertilizer use and application of manure
- Emissions from fertilizer manufacture and distribution
- Emissions from herbicide manufacture and distribution
- Energy use in field operations (e.g. tillage, harvesting)
- Energy use in fodder and feed processing on farm
- Energy use in fodder and feed transport to the farm
- N<sub>2</sub>O emissions from crop residue management
- CO<sub>2</sub> emissions from land use change.

To avoid double-counting of N<sub>2</sub>O emissions from manure deposit on pasture, these emissions were accounted for in manure management systems, and no feed emission factor was estimated for grazed pasture.

The survey identified more than 50 fodder and feed types used in the surveyed households. There are few publications from Sub-Saharan Africa estimating feed emissions. Estimated emission factors for three crops are available from the FAO LEAP GHG database.<sup>6</sup> The survey included questions to enable estimation of emissions in on-farm production, transport and processing of fodder and feeds produced on-farm. This data was used to estimate emission factors per kg of Napier grass and 14 other types of grass; 7 forms of maize crop residue used as feed; and oat residue. Other emission factors were taken from the literature. For newly estimated feed emission factors and for those taken from other sources, mass allocation was used to allocate emissions to feed as opposed to other uses. The parameter values used in calculating fodder emission factors from the baseline survey data are shown in Table 10. The feed emission factors used are shown in Appendix 6, Table A6.8.

**Table 10. Data sources used to calculate feed emission factors from the baseline survey data**

Parameter	Value used	Data source
Herbicide components	Various	Manufacturers' websites
Herbicide component emission factors	Various	GREET LCA database <sup>7</sup>
Fertilizer components	Various	Kenya Bureau of Standards product specifications
Fertilizer production emission factors	CAN: 1.00 kgCO <sub>2</sub> /kg product DAP: 0.73 kgCO <sub>2</sub> /kg product TSP: 0.26 kgCO <sub>2</sub> /kg product SSP: 0.26 kgCO <sub>2</sub> /kg product	Wood and Cowie (2004) GREET LCA database GREET LCA database Wood and Cowie (2004)
Fuel use emission factors	Petrol: 2.36 kgCO <sub>2</sub> e/liter Diesel: 2.71 kg CO <sub>2</sub> e/liter	Calculated using IPCC default CO <sub>2</sub> emission factors (IPCC 2006 Tables 3.2.1 and 3.2.2)
Land Use Change	Carbon loss from deforestation: 47 tC/ha Carbon loss from conversion of grassland: 9.45 tC/ha	Saatchi et al. (2011)  Don et al. (2011)

## 5.2. Estimation of farm level emissions

The procedures set out in Section 5.1 were used to estimate enteric fermentation, manure management emissions and emissions embodied in feed from each animal on farm during the survey. To estimate emissions intensity per farm, it is also required to estimate:

- Emissions from animals present during the year but that had left the farm by the time of the survey;
- The proportion of emissions attributable to animals present during the survey but that joined the herd during the year prior to the survey; and
- Emissions attributable to male and female replacement animals on farms that do not maintain sufficient animals to replace their current productive herd.

<sup>6</sup> <http://www.fao.org/partnerships/leap/database/ghg-crops/en/>

<sup>7</sup> <https://greet.es.anl.gov/>

In the final calculation of emissions per farm, male animals not used for reproduction and not part of the replacement herd are not included in estimation of farm emissions.

Before summing emissions from different GHG sources, they should be converted to CO<sub>2</sub> equivalents. This was done using the 100-year Global Warming Potentials from IPCC AR4 (i.e. methane = 25, nitrous oxide = 298) (IPCC 2007).

#### **5.2.1. Estimation of emissions from animals that have left the farm**

**Data input:** The baseline survey recorded for each animal that left the farm during the year (a) the cause of exit, (b) the type of animal and (c) the date of exit. This data is used together with the emission factors estimated in Section 5.1 to estimate emissions during the time in the year prior to the survey that they were on-farm.

**Data analysis:** The aim of analysis is to estimate the emissions attributable to each animal that left the farm during the year. First, calculate for each animal type in each feeding system, average emissions due to enteric fermentation, methane and nitrous oxide from manure management and emissions embodied in feed, summing across these emission sources. Second, calculate the proportion of the year during which each animal was present. Using the annual emissions per head and the proportion of the year on-farm, the emissions attributable to each animal that has left the farm during the year prior to the survey were calculated.

#### **5.2.2. Estimation of emissions from animals that joined the herd during the year**

**Data input:** This uses the estimated emissions (including enteric fermentation, methane and nitrous oxide from manure management and emissions embodied in feed) for each animal and data from the baseline survey on when each animal joined the herd.

**Data analysis:** For each animal that joined the herd during the year prior to the survey, estimate the proportion of the year that the animal was present. Multiply the estimated annual emission factor for that animal by the proportion of the year the animal was present on the farm. This value replaces the annual estimates previously calculated.

### 5.2.3. Emissions attributable to replacement animals off-farm

**Data input:** The baseline survey collected data on herd dynamics required to implement Equations 9-15 of the Smallholder Dairy Methodology.

**Data analysis:** Tables 11 and 12 show the parameters required for estimation of off-farm replacements and the source of data and procedures used for estimation. Subscripts  $j$  indicate variables calculated for each individual farm, and subscripts  $k$  indicate variables calculated for each stratum (i.e. feeding system).

**Table 11. Parameter required to estimate female replacements currently off-farm**

Parameter	Notes
$HS_j$	Number of mature cows on each individual farm. Use population data from the baseline survey for each household.
$AFC_j$	Average age at first calving for each farm. Calculated as average AFC for all cows on each farm
$AFC_k$	Calculated as average AFC for all farms in each production system
$CR_k$	Calculated as total number of mature animals leaving all farms in each production system ( $AE_k$ ) divided by total number of mature animals in all farms in each production system at the time of the survey ( $HS_k$ )
$NCR_k$	Calculated as number of female calves and heifers leaving all farms in each production system for any reason ( $CE_k$ ) divided by the number of female calves and heifers in all farms in each production system at the time of the survey ( $CH_k$ )
$CI_k$	Average calving interval for all cows in farms in each production system from the baseline survey
$SR_k$	Either calculate from baseline survey or assume 50%
$CM_k$	Calf mortality calculated as number of calves dying during the year on all farms in each production system divided by number of calves remaining on all farms in the production system at the time of the survey

**Table 12. Parameters required to estimate male replacements currently off-farm**

Parameter	Notes
$CB_j$	Number of bulls on each farm. Data taken from the baseline survey.
$BL_k$	Average lifetime of bulls in each production system. This may either be estimated from the age of bulls exiting the farm or from the age of bulls remaining on the farm. Because total sample of bulls in the Kenya survey was small, this was estimated as the age of the top quartile of bulls in each production system.
$CBR_j$	Number of bull replacements (i.e. male calves, immature males) kept on each farm. Data taken from baseline survey
$NCB_k$	Non-completion rate for bull replacements in all farms in each production system. Calculated as number of male calves and immature males exiting farms in each production system divided by the number of replacement males remaining on the farm at the time of the survey

Using the above data from the baseline survey, the aim of analysis is to estimate the difference between replacements required and replacements available. For males, this is the parameter  $BG_j$  and for females it is  $RG_j$  as

defined in the Smallholder Dairy Methodology. Where  $RG_j$  is positive, multiply the value for each farm by the average annual emissions (including enteric fermentation, methane and nitrous oxide from manure management and emissions embodied in feed) for heifers in each production system. Where  $BG_j$  is positive, multiply the value by the average annual emissions for male replacements in each production system. These values are then added to the estimate of annual emissions for each farm.

#### 5.2.4. Calculate emission intensity for each farm

Emission intensity per farm is calculated as the sum of emissions from all GHG sources on each farm (excluding surplus males) divided by total milk output (kg FPCM) from all animals on the farm during the year. At this stage, 127 surplus males were excluded from further analysis. Also, 14 households were dropped that had dairy cattle but did not produce milk during the year, e.g. all animals were young, leaving 383 households to construct the standardized baseline.

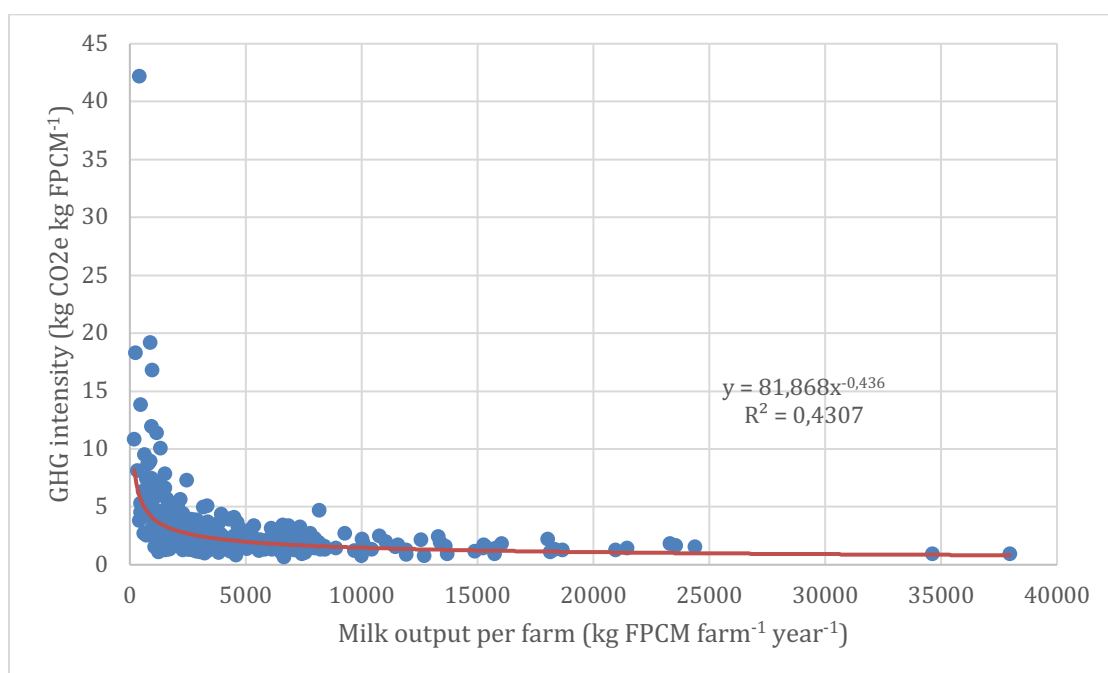
#### 5.2.5. Estimate standardized baseline

Table 13 shows the mean ( $\pm$ s.e.) of GHG intensity of milk production in the three feeding systems covered in the baseline survey. The Smallholder Dairy Methodology requires that regression analysis is used to establish a relationship between milk output per farm and GHG intensity ( $\text{kgCO}_2\text{e kg FPCM}^{-1}$ ). The resulting relationship is displayed in Figure 4. The data are best fit by a power function ( $y = 81.868x^{-0.436}$ ,  $r^2 = 0.4307$ ).

**Table 13. Mean (median, s.d.) GHG intensity of milk production ( $\text{kgCO}_2\text{e kg FPCM}^{-1}$ )**

	All feeding systems	Zero-grazing	Semi-zero grazing	Grazing only
N	383	245	96	42
Mean	3.01	2.70	3.54	3.65
Median	2.23	2.18	2.39	2.60
S.D.	3.04	1.89	4.82	3.06

**Figure 4. Relationship between GHG intensity and fat and protein corrected milk production per farm**



## 6. Accuracy and uncertainty

### 6.1. Accuracy

Sources of error in GHG estimation may include model error, sampling error and non-sampling error.

The model used to estimate GHG emissions followed the IPCC model for estimation of enteric fermentation and manure management emissions. The applicability of this model to dairy cattle in tropical conditions is a topic of ongoing research.

Non-sampling errors may arise from the use of farmer-reported values obtained using a questionnaire. For example, the error in farmer-reported milk yield estimates requires further validation (Wilkes et al. 2017). Similarly, farmer-reported volumes of forage and feed were converted to estimates of kg dry matter using standard unit conversion factors and literature values for dry matter content. In addition to representing a source of estimation error, this most likely reduces the variability between farms. Validation studies comparing estimates obtained using questionnaire methods and direct measurement methods would be useful for guiding future data collection activities.

Further errors may arise from sampling error. The sample of 429 households sampled using a cluster sampling method was set on the basis of the available budget for the pilot baseline survey. Analysis of the variability in the resulting data was used to estimate the required sample size to achieve given levels of precision with a 90% confidence interval as required by the CDM guidance referred to in the Smallholder Dairy Methodology (Annex 3). For live weight, the sampling method was to take heart girth measurements from one animal of each type present on each farm. The analysis shows that for live weight, the sample size of 429 households was sufficient to achieve a precision of  $\pm 10\%$  with a 90% confidence interval for cows, heifers and calves, but not for adult and growing males. This is because the proportions of adult and growing males in the total herd is very small, requiring that large numbers of households are sampled in order for large numbers of adult and growing males to be measured. For feed



digestibility, analysis suggests that feed digestibility for all animal types could be estimated to at least  $\pm 10\%$  precision with a sample of 429 households. This is because the variability in feed digestibility estimated using the methods set out in this document was relatively low. Milk yield is a critical parameter for estimating the standardized baseline. Analysis in Table A3.5 suggests that a sample of 429 households could estimate milk yield to at least  $\pm 10\%$  precision with a 90% confidence interval.

## 6.2. Uncertainty

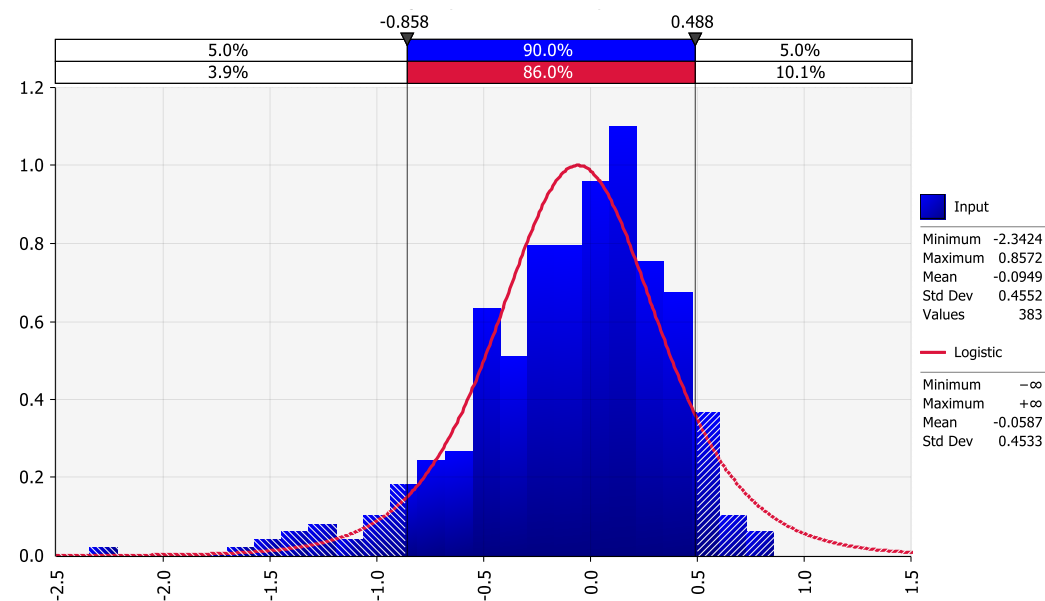
The Smallholder Dairy Methodology does not require that uncertainty is addressed. However, the CDM Methodology Panel has drafted some guidance on discounting of uncertainty, which could be used to ensure the integrity of emission reductions claimed.<sup>8</sup> The uncertainty of the curve-fitting can be measured by the root mean square error (RMSE) of prediction. RMSE is the square root of the variance of residuals and indicates absolute fit of the model to the data. RMSE was calculated to be 0.186, i.e. 18.6%.

One reason for uncertainty may be the presence of outliers. Outliers were identified by calculating the relative error of predicted emission intensity, i.e.  $[(\text{observed GHGI} - \text{predicted GHGI})/\text{observed GHGI}]$ , and cases with a relative error greater than 1 were removed. The resulting relationship is shown in showed best fit by a power function ( $y = 202.35x^{-0.535}$ ,  $R^2 = 0.5649$ ,  $\text{RMSE} = 0.164$ ). However, scenario analysis suggests that with outliers removed, estimated emission reductions would be larger than with outliers retained. Therefore, removing outliers from the standardized baseline would not give a conservative estimate of emission reductions.

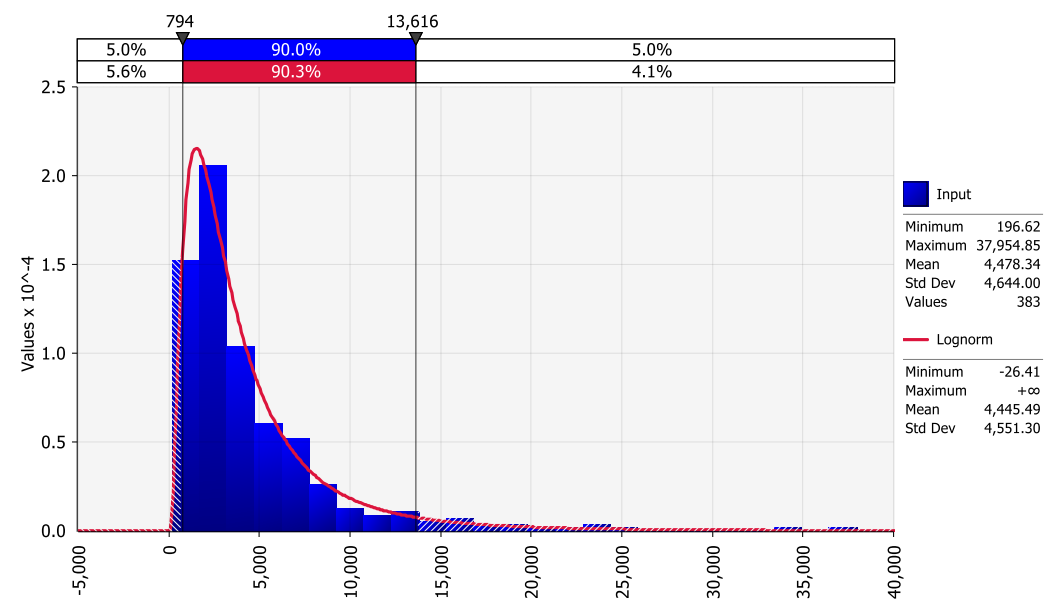
The baseline relationship in Figure 4 shows significant clustering of farms with milk yields below 5000 kg per year, and 50% of households produced less than 3000 kg per year (see also Figure 6). The relative error of prediction averaged -0.095 across all 383 households, but was higher for households with milk yields below 3000 kg (average relative error -0.137) than for households with yields greater than 3000 kg (average relative error -0.050).

<sup>8</sup> [https://cdm.unfccc.int/Panels/meth/meeting/08/032/mp\\_032\\_an14.pdf](https://cdm.unfccc.int/Panels/meth/meeting/08/032/mp_032_an14.pdf)

**Figure 5. Distribution of relative error of prediction of standardized baseline equation**



**Figure 6. Distribution of milk yield (kg FPCM per farm per year)**



Analysis of the association between relative error of prediction in Figure 4 and input variables (Table 14) suggests that prediction error is mainly associated with estimates of the mass of concentrate used per farm, and the number and proportion of cows in the herd on each farm. Numbers of adult males and heifers, manure management systems (in particular proportions deposited on pasture and managed in liquid systems), and feed digestibility also contribute to prediction error. More than half of the error of prediction is associated with levels of concentrate feed use. This suggests that improvements in feeding practices (e.g. feeding concentrate according to cows' energy needs across the lactation cycle) could be a relevant mitigation measure.

**Table 14. Stepwise regression of farm characteristics against relative error of prediction**

Term	Coef	SE Coef	P-Value	VIF	R-sq(adj)
Constant	1.218	0.375	0.001		
Kg Conc Farm	0.03289	0.00409	0.000	3.77	53.15%
Cow count	0.1911	0.0181	0.000	2.24	60.01%
Cow proportion	-0.6158	0.0818	0.000	1.67	70.73%
Adult male count	0.2605	0.039	0.000	1.12	73.59%
Heifer count	0.0925	0.0233	0.000	1.56	74.51%
Pasture dep %	0.001686	0.000615	0.006	1.04	74.83%
Roughage prop	-0.533	0.161	0.001	2.79	75.17%
DE	-0.0118	0.00502	0.019	1.61	75.44%
liquid%	0.0027	0.00124	0.031	1.12	75.68%

## 7. Discussion and recommendations

### 7.1. Results

The baseline survey resulted in estimated average GHG intensities of milk production of about 3 kgCO<sub>2</sub>e kg FPCM<sup>-1</sup> in the region of Kenya characterized by relatively more intensive dairy production (Table 13). This ranged from an average of 2.7 kgCO<sub>2</sub>e kg FPCM<sup>-1</sup> on zero-grazing farms to 3.65 kgCO<sub>2</sub>e kg FPCM<sup>-1</sup> in grazing only systems. These results are within the range reported in the literature. FAO and NZAGRC (2017) estimated 2.1 kgCO<sub>2</sub>e/kg FPCM for intensive systems and 4.1 kgCO<sub>2</sub>e/kg FPCM for semi-intensive systems, using expert judgement and the GLEAM model for inputs values and a method that combines mass and economic allocation. Weiler et al. (2014) in a study of 27 farms in Western Kenya reported a mean of 2.0 and range of 0.9-4.3 kgCO<sub>2</sub>e/kg milk, estimated using economic allocation to milk and meat. Brandt et al. (2018), estimated an average of 2.4 kgCO<sub>2</sub>e/kg FPCM across a range of agroecological systems in rural Kenya, using methods that applied no allocation rule.

Enteric fermentation accounted for about 50% of total emissions from dairy production on the farms surveyed in this study. The enteric fermentation emission factors shown in Table A6.6 can be compared to other emission factors estimated by the IPCC and by other researchers for dairy production systems in Africa (Table 15). For dairy cows, the mean emission factor estimated in this study (79.88 kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>) was higher than other published estimates for Kenya where LW and milk yield were both lower, but lower than estimates for South Africa, where LW and milk yield are both considerably higher than in this study.

**Table 15. Comparison with enteric methane emission factors from other studies**

Country	EF (kg CH <sub>4</sub> head <sup>-1</sup> year <sup>-1</sup> )	Live weight (kg)	Milk Yield (kg)
Kenya (intensive region, this study)	79.88	366.34	6.73
Kenya (intensive production system, State Department of Livestock 2019)	73.47	366.02	6.73
IPCC (Africa)	46	275	1.3
S. Africa (Total mixed ration)	132	590	10.5
S. Africa (pasture)	127	540	10.5
Kenya (Nyando)	28.3	216.3	Not reported
Kenya (Nandi)	50.6	306.9	5.11

Sources: this study; IPCC (2006); Du Toit et al. (2013); Goopy et al. (2018b); Ndung'u et al. (2019)

Feed emissions were the second largest source of emissions, accounting for 28.7% of total emissions. Global modelling using GLEAM suggests that feed emissions account for about 20% of global dairy-related emissions, but only about 10% in Sub-Saharan Africa (Opio et al. 2013). FAO and NZAGRC (2017) estimate that less than 1% of dairy-related emissions in Kenya are from feed. Weiler et al. (2014) estimated that 16% of emissions were from feed in a study of 27 farms that mostly used mixed stall-grazing feeding systems. The importance of increasing the accuracy and availability of feed emission factors in the Kenyan context is discussed in the next section.

The relationship between milk yield and GHG intensity is key to the application of the Smallholder Dairy Methodology. The baseline relationship in Figure 4 shows significant clustering of farms at milk yields below 5000 kg per year, with 50% of households producing less than 3000 kg per year (Figure 6). More than half of households surveyed had only one cow, and 50% of cows had daily average milk yields of 6 kg or less, suggesting considerable scope to reduce GHG emission intensity by increasing milk yield per cow. However, Figure 4 also indicates significant dispersion of farms around the trend line, with some having lower GHG emission intensity than predicted given their level of milk output (Figure 5). In particular, the relative error of prediction was higher at lower milk yields, indicating that farm management practices at lower yields also impact on GHG intensity. This suggests the likely existence of options to reduce GHG emission intensity other than increasing milk yield (de Vries et al. 2019), but the effects of these improvements on GHG emissions might not be captured by the Smallholder Dairy Methodology, which uses trend in milk yield as a proxy for change in GHG emission intensity.

## 7.2. Priorities for improvement in baseline survey methods

The methods described in this document represent the first attempt to implement the Smallholder Dairy Methodology's requirements for establishing a standardized baseline for GHG emissions from smallholder dairy farming in Kenya. The methods described drew on previous sampling methods and survey tools used in Kenya as well as some innovations required to implement the Smallholder Dairy Methodology. Several areas of improvement were identified, relating to sampling, methods for increasing the accuracy of estimates derived from household surveys, and improvements in estimates of feed emissions.

First, analysis of required sample size in Annex 3 suggests that for feed digestibility and milk yield, a sample size of 429 was sufficient to estimate these parameters to a precision of  $\pm 10\%$  with a 90% confidence interval as required by the Smallholder Dairy methodology. For live weight, this level of precision was obtained for cows, heifers and calves, but not for adult and growing males, which represent very small proportions of the dairy cattle population.

For weight gain of growing animal types (e.g. heifers, calves), the one-off survey method used here was not able to accurately measure animal growth (i.e. change in weight over time). The live weight data collected were analysed to estimate typical growth curves for male and female growing cattle, which were used to estimate average weight gain for each animal sub-category. The effects of this method would be to reduce the variability in weight gain achieved by animals on different farms.

Second, the methods described here did not account for consumption of milk by calves. While the survey tool did indicate whether the age at weaning of each calf on surveyed farms, no further details on feeding methods were collected. Since bucket feeding is common, the survey tool was therefore not able to distinguish between farmer-reported milk yields that did and did not account for calf consumption of milk. Future surveys should further elaborate questions to determine this.

Third, previous analysis of the uncertainty associated with enteric fermentation emissions from dairy cattle in Kenya estimated using the IPCC Tier 2 model (State Department of Livestock 2019) highlighted that the main variables contributing to uncertainty of emission factor estimates were the methane conversion factor ( $Y_m$ ), feed digestibility, live weight and weight gain, especially for cows and heifers that make up 73% of the animals enumerated in the baseline survey. In the absence of country-specific research, the IPCC default factor for  $Y_m$  was used. Feed digestibility estimates were based on a combination of feed composition data from the survey and literature values for feed chemical composition. The baseline survey tool collects farmer reported data on feeds fed to different animal types in different seasons. Analyzing the data collected, for roughage, out of 1862 reports of roughages fed by 397 households, 70% were reported as being fed to all dairy cattle, and 30% were fed to particular sub-categories of cattle. Of 669 reports of concentrates and other feed fed, 40% were fed to all dairy cattle and 60% were fed to particular sub-categories, most often (80% of cases) cows. These figures suggest that in the intensive dairy farming region of Kenya, survey tools that aim to identify feed composition for particular animal sub-categories should be able to more accurately reflect diets than methods that estimate available feed only, particularly for cows. The error associated with farmer estimates of volumes fed and their conversion to kg dry matter is unknown. Refusals of feed is known to occur (e.g. Methu et al. 2001), but were not accounted for using the methods applied here. While the overall estimates of feed digestibility for each cattle sub-category (Table A6.5) are close to the IPCC default value for dairy cattle in Africa, and are broadly consistent with other literature reports (e.g. Goopy et al. 2018b, Ndung'u et al. 2019), improvements in methods for feed composition data collection and feed chemical composition measurements should be a future priority.

In addition to the sources of uncertainty identified in previous research, the standardized baseline is likely to be sensitive to milk yield estimates, as milk yield appears in both the dependent and independent variable used to estimate the milk yield–GHG intensity relationship. Milk yield estimates were based on farmer-reported milk yields and estimates of the number of days in lactation. Some previous research has indicated that farmer-reported milk yield estimates can be quite accurate in low-yield production systems (Zezza et al. 2016), but sources of error in higher yield systems such as Kenya are not known, and factors such as extended lactations, calf suckling practices, and gendered ownership of morning and evening milk may influence the accuracy of farmer-reported milk yield estimates (Wilkes et al. 2018). Further research is required to validate the accuracy of farmer self-reported milk yields and different methods for estimating annual milk yields using recall methods.

Feed emissions also accounted for a significant proportion of total emissions. To date, there are few estimates of feed emission factors for Sub-Saharan Africa. The baseline survey collected data to enable estimation of emission factors for some key forage components, such as Napier and maize. However, missing data was common for feed production data and, as with milk yield, crop yield data estimated using farmer self-reported estimates may not be accurate, particularly for fodder crops that are harvested multiple times through the year. For concentrates and purchased feeds, the emissions embodied in many ingredients were estimated using emission factors from

FEEDPRINT, a database of emission factors developed for the Dutch livestock sector.<sup>9</sup> It can be expected that compared to Dutch feed manufacturers, energy use efficiency would be much lower in Kenya (KMT 2017), and the operating margin grid emission factor for the Netherlands (ca. 0.43 tCO<sub>2</sub>e/MWh) is lower than for Kenya (ca. 0.66 tCO<sub>2</sub>e/MWh), but production inputs used and transport distances would vary. It has not been possible to assess the effects on uncertainty of using the FEEDPRINT database as a data source. Further research is required to provide more representative and accurate estimates of the GHG intensity of fodder and feed production, processing and transport in Kenya.

### 7.3. Cost effectiveness of the methodology

The premise of the Smallholder Dairy Methodology is that, since dairy development initiatives will mostly track change in milk yields anyway, by establishing a relationship between milk yield and GHG emission intensity at the regional level, the costs of monitoring GHG emissions due to project interventions is decreased. The cost of data collection and analysis for establishing the regional standardized performance baseline was about US\$75,000. Following the Smallholder Dairy Methodology, the baseline remains valid for a crediting period of 7 years. The costs of baseline data collection are therefore much lower than for methodologies that require the collection of the full set of baseline data for each participating farm. The Kenya dairy NAMA targets about 155,000 farms, so the cost of baseline setting for each participating farm would be about US\$ 0.1. If smaller dairy mitigation initiatives are implemented in the region covered by a baseline survey, with 30,000 participating farms, the cost of baseline setting is about US\$ 0.78 per participating farm.

## 8. Conclusions

This pilot baseline survey, conducted in central Kenya, has demonstrated practical methods for setting a regional standardized performance baseline survey to measure the GHG effects of dairy development initiatives. The pilot has shown that collection and analysis of baseline data in accordance with the requirements of the Smallholder Dairy Methodology is feasible and cost-effective. The data collected through the sampling approach described here was capable of achieving precision of  $\pm 10\%$  with a confidence interval of 90% for the key parameters driving GHG emissions for most cattle types. Improvements to the data collection tool and measurement methods can further increase the accuracy of the data used. The results from central Kenya show that the regression of milk yield against GHG intensity has an uncertainty of about 18.6%. The Smallholder Dairy Methodology does not require that uncertainty is quantified, but other dairy development initiatives wishing to quantify GHG emission reductions or mitigation actions targeting the dairy sector can apply the estimated uncertainty to discount emission reductions and ensure that claims are conservative. More generally, setting standardized performance baselines for livestock or crop types may be a cost-effective approach for measuring the GHG effects of mitigation initiatives in other agricultural sub-sectors, which might be more generally applicable to support MRV of agricultural mitigation actions in developing countries.

<sup>9</sup> <http://webapplicaties.wur.nl/software/feedprintNL/index.asp>

# Appendix

## Appendix 1. Baseline data collection tool

**Note:** The actual data collection tool also collected data on management practices, gender roles and financing of farm dairy enterprises. Only the GHG-relevant contents are shown in this appendix.

**Enumerator:** Each time a household has been selected for interview, go to the household and:

- (1) Make a brief introduction:

**Good morning/afternoon. My name is \_\_\_\_\_. We are working for UNIQUE forestry and land use consultants. Together with the Kenya Dairy Board and State Department of Livestock, we are doing a survey about dairy cows and dairy production.**

**Does your household keep dairy cows?** [If No, say “thank you” and get another household from the list. If Yes:] **Does it keep more than 20 dairy cows?** If more than 20 cows, then this household should not be sampled.

- (2) Explain in more detail about the survey:

**The survey we are doing will provide information to help the State Department of Livestock and Kenya Dairy Board to design programmes of support to dairy farmers. The survey asks questions about the dairy cows that you keep, how you do feeding and other management on the farm, and the services that you use. Are you the person responsible for looking after cattle?** [If No, ask to speak to someone, e.g. household head, spouse or another adult household member, who is responsible for dairy cattle on the farm. If Yes, continue:]

- (3) Check if the person is willing to be interviewed:

**The survey will take about 1 and a half hours. Can you spare some time to talk now?** [If No, try to rearrange for later today. If yes, begin the survey]

## 1. Household identification

Only fill in if you have confirmed the household has dairy cattle and a suitable respondent is available.

Date of survey (DD/MM/YYYY) :		/ /	
Enumerator name :			
Head of household name:*			
Mobile number:*			
Time interview started :		HH:	MM:
County name :		Constituency name:	
Ward name :		Village name:	
Name of survey respondent :			
Relationship of survey respondent to household head (code a) :			
Gender of survey respondent (tick correct box):		Male <input type="checkbox"/>	Female: <input type="checkbox"/>
Household GPS Coordinates:	Latitude (N/S):	Longitude (E/W):	
<b>HH ID System: (to be filled in at data entry, not by enumerator)</b>			
Household Code (ABCDE):			
A = County, B = Constituency, C= Ward, D= Village, E=Household number			
<b>a) Respondent relationship</b>			
1 = household head, 2 = spouse, 3 = other family member, 4 = Other non-family member			

*Enumerator: explain that we will not share details about their name or phone number with anyone else, but we may need to contact them again to cross-check some of the information. That is why we ask for the name and phone number. If they are not willing to give their phone number, that is OK.*

### Quality Assurance Aspects

DATE OF QUESTIONNAIRE INSPECTION BY SUPERVISOR (dd/mm/yyyy):		/ /
Review of questionnaire:		
<b>Enumerator assessment: Fill this in AFTER you have administered the questionnaire</b>		
Assessment of quality of information: (1 = reliable, 2=unreliable)		
Explain or add any relevant comments:		
<p><b>Supervisor: Enter your comments here AFTER you have inspected the WHOLE questionnaire</b></p>		



## 2. Livestock and Cattle: Herd Structures and Dynamics

### 2.1 Keeping and ownership of dairy cattle

How many local and cross-bred/exotic are cattle kept and owned by the household? (Include calves, heifers or steers, and mature animals, male and female).

Cattle type		A=Number kept by the household	B=Number owned but kept by other households	C=Number not owned but kept by the household for others
Cattle	Local			
	Cross/exotic*			

\* "Cross" refers to a cross-bred animal which is part-exotic.

### 2.2 Cattle herd inventory

List all cattle kept on the farm and their characteristics. **Include only cattle kept by the household**, no matter whether it is owned by the household or by others. For heart girth measurements, select **one animal of each type whose age is known**, and use a chest girth tape to measure. If farmer doesn't know age or weight, enter "999".

Cattle ID		Animal type (code a)	Breed (code b)	Age (years) (don't know=999)	Who owns it? (code c)	For animals sampled for measurement		
						Farmer weight estimate (kg)	Heart girth (cm)	Is body condition 'poor'? (N=0, Y=1)*
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
a) Animal type				b) Breeds			c) ownership	
1 = Bulls (>3 yrs )				1= Holstein Friesian (pure/mixed)			1 = Household head	
2 = Castrated adult males (oxen>3 yrs)				2= Ayrshire (pure/mixed)			2 = spouse	
3= Immature males (< 3 yrs)				3= Jersey (pure/mixed)			3 = other household female	
4= Cows (calved at least once not lactating)				4=Guernsey (pure/mixed)			4 = other household male	
5= Cows (lactating)				5= Cross-bred unknown			5 = joint hh male & female	
6= In-calf (cow lactating)				6=Sahiwal			6 = Non-household member	
7=Female calves (between 8 wks & <1yr)				7= Boran		**Poor' body condition is indicated by very prominent pin bones with a deep V shape cavity below the tailhead and no fatty tissue under the skin.		
8=Male calves (between 8 wks & <1yr)				8= Local zebu				
9= Heifers(female ≥1yr,have not calved)				9= Others specify				
10= Pre weaning females (<8 wks)								
11= Pre weaning males (<8 wks)								
12= in-calf heifer								

2.3 Have any cattle (including calves, heifers, cows or bulls) exited the herd kept on the farm during the past 12 months? **No** (=0) or **Yes** (=1). If No, go to 2.4.

[illegible]

2.4 Have any new cattle joined the herd on the farm or were any calves born in the last 12 months? No \_\_\_\_\_ (=0) or Yes \_\_\_\_\_ (=1). If No, go to 3. (If Yes, give individual details on all cattle that were born, purchased or obtained)

[illegible]

### 3. Cows, cow milk production and milk sales

In this section **do not include** any information on goat milk or milk of other animals. **Only dairy cows and cow milk** are considered.

### 3.1 Dairy cow profiles

For each cow kept on the farm fill in each column. If farmer doesn't know age at first calving, parity or other answers, enter "999". \*For milk yield, if currently lactating, ask for maximum and minimum yield of current lactation; if currently dry, ask for maximum and minimum yield of previous lactation.

[illegible]

## 4. Feeding

### 4.1 Defining the seasons

**In your area, which months are considered ‘dry season’ and which months are considered ‘wet season’?**

(Enumerator: put a tick in the appropriate box for each season. If there are long rains and short rains, both are wet season. Dry seasons are any months between the rainy seasons)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry												
Wet												

### 4.2 How do you keep your cattle in the dry and the rainy season?

	Rainy season (code a)	Dry season (code a)
Bulls		
Castrated adult males (oxen>3 yrs)		
Immature males (< 3 yrs)		
Cows (calved at least once not lactating)		
Cows (lactating)		
In-calf (cow lactating)		
Heifers (female $\geq 1$ yr, have not calved)		
In-calf heifer		
Female calves (between 8 wks & <1yr)		
Male calves (between 8 wks & <1yr)		
Pre-weaning calves (<8 wks)		
<b>a) Rainy season and dry season codes</b>		
1= Only grazing (free-range or tethered) 2= 50:50 grazing-stall 3= Only stall feeding (zero grazing) 4= 51-69% grazing	5= 70-90% grazing 6= 51-69% stall feeding 7= 70-90% stall feeding	

### 4.3 If grazing or semi-grazing

	Rainy season	Dry season
When grazing, are the cattle tethered? (No=0, Yes = 1)		
Is the pasture grazed natural pasture (=1) or improved pasture (=2)?		
Is the route and place they graze relatively flat? (Code a)		
How much distance to get to where they graze? (km)		
<b>Code (a) grazing terrain</b>		
1=relatively flat 2= a little hilly (but not much extra effort for cattle) 3= very hilly (extra effort for cattle)		

#### 4.4 What fodder and crop residues do you feed to your cattle? (include both grazing and fed)

##### a) Main fodder and crop residue fed during the wet season

Feed type (Code a)	Source (grown on farm = 1, purchased = 2)	1=Fresh or 2=dry	Any treatment? (code d)	Cattle type (Code b)	Unit of feed (Code c)	Frequency (code e)	Number of units fed	Number of months this type of feed is fed	If purchased:	
									Distance transported (km)	How transported (Code f)

##### b) Main fodder and residue fed during the dry periods

Feed type (Code a)	Source (grown on farm = 1, purchased = 2)	1=Fresh or 2=dry	Any treatment? (code d)	Cattle type (Code b)	Unit of feed (Code c)	Frequency (code e)	Number of units fed	Number of months this type of feed is fed	If purchased:	
									Distance transported (km)	How transported (Code f)

<b>a) Fodder type</b>	21= Dry maize stovers 22= Dry maize cob, kernel, stover 23= Maize thinnings 24= Wheat residue 25= Barley residue 26= Oat residue 27= Rice residue 28= Sorghum residue 29= Millet residue 30= Bean residue 31= Cow pea residue 32= Soya residue 33= Sweet potato vines 34= Cassava leaves 35= Potato peelings 36= Banana stems and residue 37= Vetch 38= Other residue (specify) 39= Silage (maize) 40= Silage (other grass) 41= vegetable waste	<b>b) Cattle type</b>	<b>c) Unit of feed</b>
1= Napier grass 2= Blue buffalo grass 3= White buffalo grass 4= Kikuyu grass 5= Star grass 6= Guinea grass 7= Giant setaria 8= Giant panicum 9= Boma Rhodes 10= Calliandra 11= Lucerne 12= Desmodium 13= Lucaenia 14= Sesbania 15= Other grasses 16= Weeds 17= Cabbage 18= Other fodder (specify) 19= Green maize stovers 20= Green maize cob, kernel, stover		1 = Bulls (>3 yrs ) 2 = Castrated adult males (oxen>3 yrs) 3= Immature males (< 3 yrs) 4= Cows (calved at least once not lactating) 5= Cows (lactating) 6= In-calf (cow lactating) 7=Female calves (between 8 wks & <1yr) 8=Male calves (between 8 wks & <1yr) 9= Heifers(female ≥1yr,have not calved) 10= Pre weaning females (<8 wks) 11= Pre weaning males (<8 wks) 12= in-calf heifer 13 = all animal types	1= Hours grazed 2= Kg 3= Debe 4= Kasuku can loose 5= Kasuku can compacted 6= Jerry can 7= Wheelbarrow 8= Standard sack 9= Donkey cart load 10= Bale 11= Man's load 12=woman's load 13=other (specify)
<b>d) Treatment</b>		<b>e) Frequency</b>	<b>f) Transport</b>
0= No treatment 1= Turned into hay 2= Chopped using panga 3= Hand chopped using chaff cutter 4= Motorized chopping using a pulveriser 5= Pit silage without additives 6= Tube silage without additives 7= Pit silage with additives (urea, molasses etc.) 8= Tube silage with additives (urea, molasses etc.) 9= Grazed 10= Other, specify		1=Year 2=Month 3=Week 4=Days 5= Hours per day	1=on foot 2=donkey or donkey cart 3=bicycle 4=motorbike 5=car 6=small truck (≤1 tonne) 7=large truck (1-5 tonne)

4.5 Do you feed cattle concentrate feeds, by-products and/or mineral supplements? No \_\_\_\_\_ (=0) or Yes \_\_\_\_\_ (=1). If No go to Section 4.7

What is fed? (feed type, code b)	Which animal types are fed with it? (code a)	How many months of the year do you feed these?	Unit of feed volume (Code c)	units fed per animal per day		If lactating cow, and varies by production, indicate range of feed units per animal per day		Made on-farm (=1) or purchased (=2)?	If purchased	
				Wet season	Dry season	min	max		Distance transported (km)	How transported (Code f)
<b>a) Cattle type</b>			<b>b) Feed type</b>			<b>c) Feed volume unit</b>		<b>f) transport</b>		
1 = Bulls (>3 yrs ) 2 = Castrated adult males (oxen>3 yrs) 3= Immature males (< 3 yrs) 4= Cows (calved at least once not lactating) 5= Cows (lactating) 6= In-calf (cow lactating) 7=Female calves (between 8 wks & <1yr) 8=Male calves (between 8 wks & <1yr) 9= Heifers(female ≥1yr,have not calved) 10= Pre weaning females (<8 wks) 11= Pre weaning males (<8 wks) 12= in-calf heifer 13 = all animal types			1= Commercial dairy meal 2= Home-made dairy meal / supplement 3= Bran (wheat) 4= Bran (maize) 5= Maize germ 6= Sesame seed by-product 7= Cotton seed by-product 8= Copra by-product 9= Sunflower seed by-product 10= Brewers waste 11= Grape marc 12= Molasses 13= Mineral blocks 14=Pyrethrum marc 15= Other specify			1= Kg 2= Kasuku can 3= Jerry can 4= Debe 5= Days - smaller sack 6= Days - larger sack		1=on foot 2=donkey or donkey cart 3=bicycle 4=motorbike 5=car 6=small truck (≤1 tonne) 7=large truck (1-5 tonne)		



4.6 If own dairy meal/supplement made on-farm, what do you incorporate?

[illegible]

#### 4.7 What machinery and fuels are used in fodder preparation?

Do you use any machine and fuel for fodder preparations? No \_\_\_\_\_ (=0) or Yes \_\_\_\_\_ (=1).

If No go to Section 4.8. Note: this table is for fodder, the next table is for feed. Fodder type should match with fodder with treatment in Tables 4.4.a and 4.4.b.

Type of machine (code a)	Type of fuel or energy source (code b)	Fodder type with treatment (code c)	Units of fodder made (code d)	Number of units of fodder made	Unit of fuel or energy consumed (code d)	Number of units energy consumed per unit of fodder treated
<b>a) Machine type</b>	<b>b) Fuel / energy type</b>	<b>d) units</b>	<b>e) fuel volume consumed</b>			
1= Chaff cutter 2= Pulverizer 3= Feed mill 3= Other (specify)	1=by hand 2= diesel 3= electricity 4= LPG / kerosene 5= biogas 6= other (specify)	2= Kg 3= debe 4= bale 5= day 6= week 7= month 8=year 9=other (specify)	1= kg 2= liters 3= kWh 4= Other (specify)			
<b>c) Fodder type</b>			21= Dry maize stovers 22= Dry maize cob, kernel, stover 23= Maize thinnings 24= Wheat residue 25= Barley residue 26= Oat residue 27= Rice residue 28= Sorghum residue 29= Millet residue 30= Bean residue 31= Cow pea residue 32= Soya residue 33= Sweet potato vines 34= Cassava leaves 35= Potato peelings 36= Banana stems and residue 37= Vetch 38= Other residue (specify) 39= Silage (maize) 40= Silage (other grass) 41= vegetable waste			
1= Napier grass 2= Blue buffalo grass 3= White buffalo grass 4= Kikuyu grass 5= Star grass 6= Guinea grass 7= Giant setaria 8= Giant panicum 9= Boma Rhodes 10= Calliandra 11= Lucerne 12= Desmodium 13= Lucaenia 14= Sesbania 15= Other grasses 16= Weeds 17= Cabbage 18= Other fodder (specify) 19= Green maize stovers 20= Green maize cob, kernel, stover						

#### 4.8 What machinery and fuels are used in feed preparation?

If none go to Section 4.9.

Note: this table is for feed (i.e. dairy meal or concentrate supplement) made on-farm as described in Table 4.6.

Type of machine (code b)	Type of fuel or energy source (code c)	Units of feed made or frequency of energy use (code d)	Number of units of feed made	Unit of fuel or energy consumed (code e)	Number of units energy consumed per unit of feed made
b) Machine type	c) Fuel / energy type	d) units	e) fuel volume consumed		
1= Chaff cutter 2= Pulverizer 3= Feed mill 4= Other (specify)	1= by hand 2= diesel 3= electricity 4= LPG / kerosene 5= other (specify)	2= Kg 3= debe 4= bale 5= day 6= week 7= month 8=year 9=hours* 10=other (specify)	1= kg 2= liters 3= kWh 4= kW * 5=Other (specify)		

\* If the respondent does not know how many kWh of electricity are used, an alternative is to look at the power rating (wattage) on the machine, and ask how many units of feed are processed in 1 hour by the machine?

## 4.9 About cropping on the farm

### 4.9.1 What land resources are owned and how has their use changed?

List all parcels of land used by the household and ask whether in the last 20 years, each parcel has changed from another type of vegetation. (Land use change does not include change in crop type - see code c for examples of land use change). If any answer is “don’t know”, enter “999”.

Parcel* ID	Is it now used for crops or fodder? (crops = 1, fodder = 2, both = 3)	Size of this parcel (acres)	Tenure type (Code a)	If parcel is <u>owned</u> , who owns (Code b)	Land-use change (0=No, 1=Yes)	Portion changed (% of parcel)	Land use change (code c)	Years undisturbed prior to change	Years since change
1									
2									
3									
4									
5									
6									
7									
8									
9									
a) Type of tenure		b) If owned, name on title/certificate:			c) Land use change				
1= Title deed 2= Owned but not titled 3= Public land 4= Rented-in/ sharecropped / contracted 6= Owned by relative 7= Other (specify)		1= Household head 2= Spouse 3= Other male 4= Other female 5= Joint (household head & spouse) 6= Not-owned 7= Other (specify)			1= Forest to grassland 2= Forest to arable 3= Grassland to forest 4= Arable to forest 5= Arable to infrastructure^ 6= Grassland to infrastructure^ 7= Grassland to arable 8= Swamp to grassland 9= Swamp to arable 10= Swamp to infrastructure^ 11=Other 12=Arable to grassland				

\*parcel is one contiguous plot of land. One parcel can contain more than one plot.

^ Infrastructure refers to any built environment or structure.

#### 4.9.2 Area of fodder crops planted

Fodder type (Code a)	Area of sub-plot (acres)	Is it intercropped? (Yes =1, No=0)	If yes, % of sub-plot planted to fodder	Unit of harvest (code b)	Total harvest in last 12 months (number of units)
<b>a) Fodder crop type</b>			<b>b) unit of harvest</b>		
1= Napier grass 2= Blue buffalo grass 3= White buffalo grass 4= Kikuyu grass 5= Star grass 6= Guinea grass 7= Guinea setar 8= Giant panicum 9= Boma Rhodes 10= Elmha Rhodes 11= Calliandra	12= Lucerne 13= Desmodium 14= Lucaenia 15= Sesbania 16= Maize 17= Beans 18= Wheat 19= Vetch 20= Sorghum 21= Oat 22= Sweet potato 23= Banana			1= Kg 2= Debe 3= Kasuku can loose 4= Kasuku can compacted 5= Jerry can 6= Wheelbarrow 7= Standard sack 8= Donkey cart load 9= Bale 10= Man's load 11=woman's load	

### 4.9.3 Fodder grown on farm

From Section 4.4, choose two major types of **perennial fodder crop grown on the farm**. Tell us about inputs used in the last year.

No.		Fodder crop 1	Fodder crop 2
1	Type of fodder crop (name)		
2	Parcel ID where it is grown		
	<i>Choose one sub-plot where it is grown and ask:</i>		
3	Area (in acres) of the sub-plot		
4	Is this is the only crop in that parcel? No=0, yes = 1		
5	If No, what % of the parcel is grown to this crop?		
6	If No, is it intercropped with legumes? No=0, yes = 1		
7	For perennials, how many years ago was the current stand planted?		
	<b>About buying inputs:</b>		
8	How far is your main source of input for fodder production (seeds, fertilizer and other agro-inputs?) (km)		
9	How do you transport them to the homestead? (code g)		
	<b>Before planting</b>		
10	herbicide type used (code d)		
11	herbicide measurement unit (code a)		
12	herbicide volume used		
	<b>Planting (only fill in this section if planted in last 12 months; if intercropped, only fill in input use for the fodder crop, not the other crops in the plot):</b>		
13	Seed or canes measurement unit (code a)		
14	Number of units planted		
15	Tillage method (by hand = 0, by machine = 1)		
16	If machine, what fuel type (code f)		
17	Fuel measurement unit (code a)		
18	Total fuel used for tillage for this crop in the year		
19	Farm yard manure type applied (code b)		
20	Farm yard manure units of measurement (code a)		
21	Farm yard manure used (units applied)		
22	Farm yard manure placement method (code c)		
23	Compost units of measurement (code a)		
24	Compost units used		
25	Compost placement method (code c)		
26	Fertilizer type A used (code b)		
27	Fertilizer measurement unit (code a)		
28	Fertilizer volume used		
29	Fertilizer placement method (code c)		
30	Fertilizer type B used (code b)		
31	Fertilizer measurement unit (code a)		
32	Fertilizer volume used		
33	Fertilizer placement method (code c)		
	<b>After planting (fill in for the last 12 months):</b>		
34	Farm yard manure type applied (code b)		
35	Farm yard manure units of measurement (code a)		
36	Farm yard manure used (units applied)		
37	Farm yard manure placement method (code c)		
38	Fertilizer type A used (code b)		

39	Fertilizer measurement unit (code a)		
40	Fertilizer volume used		
41	Fertilizer placement method (code c)		
42	Fertilizer type B used (code b)		
43	Fertilizer measurement unit (code a)		
44	Fertilizer volume used		
45	Fertilizer placement method (code c)		
46	herbicide type used (code d)		
47	herbicide measurement unit (code a)		
48	herbicide volume used		
49	Fungicide/insecticide type used (code e)		
50	Fungicide/insecticide measurement unit (code a)		
51	Fungicide/insecticide volume used		
52	Lime used/year (kg)		
53	Is the plot irrigated? (no=0, yes = 1)		
54	If yes, how many m <sup>3</sup> used per growing season?		
55	If the water is pumped, what fuel type is used to power the pump?(code f)		
56	Fuel measurement units (code a)		
57	Units of fuel used per year for irrigation		
	<b>Harvest:</b>		
58	Harvest measurement unit (code a)		
59	Fresh (=1) or dry (=0)?		
60	Total units harvested in the last 12 months		
61	Harvest method (by hand = 0, by machine = 1)		
62	If harvested by machine, fuel type (code f)		
63	Harvest machine fuel measurement unit (code a)		
64	Total fuel used for harvest in the year		
65	Distance transported to homestead (meters)		
66	Transport method (code g)		
64	If transported by machine, fuel type (code f)		
65	Harvest transport fuel measurement unit (code a)		
66	Total fuel used for transport of harvest in the year		

### Codes for 4.9.3

<b>a) measurement units</b> 1= Kg 2= Debe 3= Kasuku can loose 4= Kasuku can compacted 5= Jerry can 6= Wheelbarrow 7= Standard sack 8= Donkey cart load 9= Bale 10= Man's load 11=woman's load 12= liters 13= Hand-cart load 14= Pick-up load 15= Wheelbarrow load 16= Standard kiondo 17= Kasuku 18= 20-kg bucket / debe 19= 50kg debe 20= Kimbo/Kasuku tin 21= Lorry 22= canes (e.g. for fodder grasses) 23=Other specify	<b>b) fertilizer type</b> 1= CAN 2= DAP 3= TSP 4= SSP 5= Cattle manure (slurry) 6= Cattle manure (wet) 7= Cattle manure (dry) 8= Poultry manure 9= coffee husks 10= Other (Specify)  <b>d) herbicide type</b> 1= Round up (NS-PE) 2=Gramoxone (NS -PE) 3= Buctril (blw-PE) 4= Wound out 480 SL (NS-PE) 5= Primag ram Gold (pre & early PE –SEL) 6=Lumax 7= Guardian max 8= Sencor 9= 72% Diammie 10= Herbikill 11= Other
<b>c) fertilizer placement method</b> 1= broadcast 2= incorporate 3= apply in solution with water 4= broadcast or incorporate then flood	<b>e) fungicide/insecticide type</b> 1= TWIGA-EPONIL (Broad based) 2= bellis 3= Ogor 40 EC 4= Actellic Super 5= DUDUTHRIN 1.75 ECA 6= Dimethothe 4 E 7=Other
<b>f) fuel type</b> 1=by hand 2= diesel 3= electricity 4= LPG / kerosene 5= other (specify)	<b>g) transport method</b> 1=on foot 2=donkey or donkey cart 3=bicycle 4=motorbike 5=car 6=small truck ( $\leq 1$ tonne) 7=large truck (1-5 tonne)



## 5. Other dairy management practices

### 5.1 Water

Tell us about how you provide water for dairy cattle on the farm:

What is your water source for feeding cattle (code a)		
If off-farm, do you pay for the water (No=0, Yes=1)		
If off-farm, how far away is the water source (meters)		
If off-farm, how do you transport it to the homestead? (Code b)		
<i>If water is pumped:</i>		
Fuel type used (code c)		
Unit of water flow (code d)		
Fuel use per unit of water pumped		
How is water offered to the cattle?	Dry season	Wet season
Trough (=1), bucket (=2) or bowl (=3)		
How big is each trough, bucket or bowl (liters)		
Number of troughs, buckets or bowls used on the farm		
Is water continuously available (=1) or only when provided (=2)?		
If, only when provided: How many times per day is water provided?		
How much is provided each time (liters)		
<b>a) water sources</b>	<b>b) transport method</b>	
1= on farm piped water 2= on farm well or spring 3= off-farm piped water 4= off-farm well or spring 5= off-farm other (specify)	1=on foot 2=donkey or donkey cart 3=bicycle 4=motorbike 5=car 6=small truck ( $\leq 1$ tonne) 7=large truck (1-5 tonne) 8= piped to farm	
<b>c) fuel type used</b> 1=by hand 2= diesel 3= electricity from the grid 4= LPG / kerosene 5= solar electricity 6= other (specify)	<b>d) units of water</b> 1=liters 2=kg 3= cubic meters 4= jerry can 5= other (specify)	

## 5.2 Manure management

Please tell us what % of cattle manure is used in different ways in the dry and wet seasons (999 if respondent refuses or doesn't know)

	Dry season (enter % for each use)	Wet season (enter % for each use)
Left where deposited on pasture		
Collected and spread on grass/pasture every day		
Left in the area where cows are kept		
Collected and stored in piles for several months before use		
Composted		
Stored as a liquid or slurry		
Biodigester		
Burnt for fuel		
Sold		
	<b>Total should be 100%</b>	<b>Total should be 100%</b>

## 5.3 Draft animal utilization

Indicate what tasks your household uses draft animals for and how much they work in the year.

Tasks that use draft animals	Animal type used (code a)	Use own animal (=1) or animal rented or borrowed from others (=2)?	Number of days used in the year	Number of hours working per day
<b>a) animal type: 1= Ox    2= Donkey    3= other (specify)</b>				

Time interview <b>ended</b> :	HH:		MM:		
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**To be answered privately by the enumerator immediately following the interview**

1. In your opinion, how did you establish rapport with this respondent [\_\_\_\_]  
1 = with ease  
2 = with some persuasion  
3 = with difficulty  
4 = it was impossible
2. Overall, how did the respondent give answers to your questions? [\_\_\_\_]  
1 = willingly  
2 = reluctantly  
3 = with persuasion  
4 = it was hard to get answers
3. How often do you think the respondent was telling the truth? [\_\_\_\_]  
1 = rarely  
2 = sometimes  
3 = most of the times  
4 = all the time

I certify that I have checked the questionnaire two times to be sure that all the questions have been answered, and that the answers are legible.

Signed: \_\_\_\_\_

Date \_\_\_\_/\_\_\_\_/\_\_\_\_

## Appendix 2. Smallholder Dairy Methodology parameters and data obtained from the baseline survey tool

<b>Parameter</b>	<b>Milk<sub>fat</sub></b>
Unit:	%/kg milk
Description:	Fat content of milk
In survey?	No, use literature values.
Comment:	
<b>Parameter</b>	<b>Milk<sub>protein</sub></b>
Unit:	%/kg milk
Description:	Protein content of milk
In survey?	No, use literature values.
Comment:	
<b>Data Parameter</b>	<b>DE%</b>
Data Unit:	Proportion
Description:	Digestible energy expressed as a proportion of gross energy
In survey?	Tables 4.4 and 4.5 collect data on diet composition
Comment:	Feed digestibility of each fodder or feed type is estimated using values from the literature or other databases.
<b>Data Parameter</b>	<b>Y<sub>M</sub></b>
Data Unit:	%
Description:	Methane Conversion Factor
In survey?	No, use IPCC values.
Comment:	
<b>Data Parameter</b>	<b>C<sub>f<sub>i</sub></sub></b>
Data Unit:	MJ * head <sup>-1</sup> * day <sup>-1</sup>
Description:	Coefficient for each animal category used in determining net energy for maintenance
In survey?	No.
Comment:	IPCC Ch 10 Table 10.4. Data on category of animal is in survey Table 2.2
<b>Data Parameter</b>	<b>C<sub>a</sub></b>
Data Unit:	unitless
Description:	Coefficient corresponding to animal's feeding situation used in determining net energy for activity
In survey?	No. use IPCC value
Comment:	Data on stall feeding/grazing is in survey Table 4.2
<b>Data Parameter</b>	<b>Hours<sub>i</sub></b>
Data Unit:	Hours <sup>-1</sup> * head <sup>-1</sup> * day <sup>-1</sup>
Description:	Number of hours of work per day for the <i>i</i> th animal
In survey?	Yes. Survey Table 5.4

Comment:	Survey values should then be averaged over the year to get estimate of average daily hours worked
<b>Data Parameter</b>	<b>C<sub>pregnancy</sub></b>
Data Unit:	Unitless
Description:	Coefficient used in calculating net energy for pregnancy
In survey?	No, use IPCC value.
Comment:	Number of days in the year each cow was pregnant can be estimated from date of last calving and calving interval in survey Table 3.1
<b>Data Parameter</b>	<b>LW</b>
Data Unit:	kg/animal
Description:	Live weight of the animals in the population
In survey?	Yes, survey Table 2.2, where 1 animal of each type is sampled using heart girth measurement.
Comment:	Heart girth measurement can be converted to LW estimate using validated conversion equations
<b>Data Parameter</b>	<b>MW</b>
Data Unit:	kg/animal
Description:	Mature body weight of an adult female in moderate body condition
In survey?	Yes. Tables 2.2 and 3.1
Comment:	Mature is taken as LW after 4 <sup>th</sup> parity. LW data is in Table 2.2, parity data is in Table 3.1. HG measurements should be on animals in 'moderate' condition, so Table 2.2 asks to note whether the animal is in 'poor condition', and if so, these measurements can be excluded.
<b>Data Parameter</b>	<b>WG</b>
Data Unit:	kg day <sup>-1</sup>
Description:	Average daily weight gain of the animals in the population
In survey?	No. To be calculated from measured LW of cattle at different ages
Comment:	
<b>Data Parameter</b>	<b>C<sub>g</sub></b>
Data Unit:	Unitless
Description:	Coefficient used in calculating net energy for growth
In survey?	No, use IPCC values.
Comment:	
<b>Data Parameter</b>	<b>EF<sub>FEED</sub></b>
Data Unit:	kg CO <sub>2</sub> e/ kg feed
Description:	Emission factor for embodied emissions in each feed type

In survey?	Table 4.9.3 is used to collect data for LCA on on-farm fodder production; Table 4.7 collects energy use data on fodder preparation, Table 4.8 collects energy use data on feed processing on-farm. 4.9.1 collects data on land use change.
Comment:	This will enable estimation of EF feed for a small number of fodder types and feed types. The other feed EF values can be obtained from published literature or other databases.
<b>Data Parameter</b>	<b>Feed</b>
Data Unit:	kg feed (each type) * year <sup>-1</sup>
Description:	Quantity of each type of feed (roughage, concentrate and organic or inorganic supplements) consumed by the animals
In survey	Yes. Table 4.4 collects data on fodder and crop residues fed, and Table 4.5 on concentrate feeds and other supplements
Comment:	
<b>Data Parameter</b>	<b>VS<sub>i</sub></b>
Data Unit:	(kg dry matter * head <sup>-1</sup> * day <sup>-1</sup> )
Description:	Daily Volatile Solids excreted per animal
In survey?	No.
Comment:	Volatile solids calculated using IPCC Tier 2 method (Equation 10.24), which requires GE and DE% from the survey, and urinary energy and ash content from IPCC or literature values.
<b>Data Parameter</b>	<b>B<sub>0,i</sub></b>
Data Unit:	(m <sup>3</sup> CH <sub>4</sub> * kg <sup>-1</sup> of VS excreted)
Description:	Maximum methane producing capacity
In survey?	No.
Comment:	Default values for the maximum methane producing capacity can be found in Table 10A-4 of IPCC 2006 Vol.4 Ch. 10, Annex 10A.2, page 10.77
<b>Data Parameter</b>	<b>MCF<sub>s,i</sub></b>
Data Unit:	unitless
Description:	Methane conversion factor specific to manure management systems
In survey?	No
Comment:	MCF can be found in Table 10.17, IPCC 2006 Vol.4 Ch. 10. Need to match sample sites with annual average temperature to select appropriate value from the IPCC tables.
<b>Data Parameter</b>	<b>MS<sub>s,i</sub></b>
Data Unit:	Unitless

Description:	Fraction of the manure handled using the manure management system
In survey?	Yes, Table 5.2.
Comment:	Manure management categories in Table 5.2 are matched with IPCC categories in IPCC Table 10.17
<b>Data Parameter</b>	<b>AFC<sub>k</sub></b>
Data Unit:	Months <sup>-1</sup>
Description:	Average age at first calving of cows in stratum <i>k</i>
In survey?	Table 3.1 for all cows on farm.
Comment:	
<b>Data Parameter</b>	<b>AE<sub>k</sub></b>
Data Unit:	Head
Description:	Number of mature females exiting farms in stratum <i>k</i> due to culling, sales, gifts or other reasons in the year prior to the baseline survey
In survey?	Table 2.3 collects data on all cattle exiting by animal category
Comment:	
<b>Data Parameter</b>	<b>CE<sub>k</sub></b>
Data Unit:	Head
Description:	Number of calves and heifers exiting farms in stratum <i>k</i> due to culling, sales, gifts or other reasons in the year prior to the baseline survey
In survey?	Table 2.3 collects data on all cattle exiting by animal category
Comment:	
<b>Data Parameter</b>	<b>CH<sub>k</sub></b>
Data Unit:	Head
Description:	Number of calves and heifers on farms in stratum <i>k</i> in the baseline survey
In survey?	Table 2.2 collects data on all cattle by animal type
Comment:	
<b>Data Parameter</b>	<b>SR<sub>k</sub></b>
Data Unit:	Ratio
Description:	Sex ratio of calves born in stratum <i>k</i> in the baseline survey
In survey?	Table 2.4 collects data on calves born in the year by sex.
Comment:	Table 2.4 may not collect still born by sex. Can use literature values, if available.
<b>Data Parameter</b>	<b>CD<sub>k</sub></b>
Data Unit:	Head
Description:	The number of calves on farms in stratum <i>k</i> that died in the year prior to the baseline survey
In survey?	Table 2.3 collects data on all cattle exiting by animal category

Comment:	
<b>Data Parameter</b>	<b>CB<sub>k</sub></b>
Data Unit:	Head
Description:	The number of calves born on farms in stratum <i>k</i> in the year prior to the baseline survey
In survey?	Table 2.4 collects data on calves born in the year.
Comment:	
<b>Data Parameter</b>	<b>BL<sub>k</sub></b>
Data Unit:	Years
Description:	Average working lifetime of a bull in stratum <i>k</i>
In survey?	Tables 2.2 and 2.3
Comment:	Table 2.3 collects data on all animals by type exiting the farm and notes their age. Average working lifetime can be estimated from age of bulls exiting the farm and age of bulls on farm
<b>Data Parameter</b>	<b>NCB<sub>k</sub></b>
Data Unit:	%
Description:	Average non-completion rate for bull replacements on farms in stratum <i>k</i> in the baseline survey
In survey?	Table 2.3
Comment:	Bull replacements exiting farm can be identified from Table 2.3
<b>Data Parameter</b>	<b>REDD+ Programme</b>
Data Unit:	Unitless
Description:	Existence and extent of a REDD+ programme in the geographic region related to feed for the project
In survey?	No
Comment:	For list of REDD+ programme countries, see <a href="http://theredddesk.org/countries/">http://theredddesk.org/countries/</a>
<b>Data Parameter</b>	<b>LK<sub>LUC,t</sub></b>
Data Unit:	tCO <sub>2</sub> e * year <sup>-1</sup>
Description:	Leakage due to land use change due to changing demand for feedstuffs due to project implementation in project year <i>t</i>
In survey?	No
Comment:	Only needed for project, not for baseline.
<b>Data Parameter</b>	<b>Dairy farm stratum</b>
Data Unit:	Unitless
Description:	The project proponents shall identify the dairy farm stratum (e.g. grazing, stall & grazing or zero-grazing) to which each project area can be allocated.
In survey?	Table 4.1 characterizes farms by grazing, stall & grazing or zero-grazing



Comment:	Analysis of average GHGI per farm can investigate whether feeding system or agroecological zone or other categorization leads to statistically significant differences in average GHGI per farm.
<b>Data Parameter</b>	<b>Annual total milk yield per farm</b>
Data Unit:	kg milk * farm <sup>-1</sup> * year <sup>-1</sup>
Description:	Total uncorrected volume (in litres) of milk produced per farm per year
In survey?	Table 3.1 collects data on milk production by each cow
Comment:	Table 3.1 asks for estimate of maximum and minimum daily yield in a lactation. This can be used to estimate an average daily yield per cow.
<b>Data Parameter</b>	<b>Number of lactating and dry cows per farm (HS<sub>j</sub>)</b>
Data Unit:	Head
Description:	The number of lactating and dry cows in each farm in each year
In survey?	Table 2.2
Comment:	
<b>Data Parameter</b>	<b>Number of bulls maintained per farm (CB<sub>j</sub>)</b>
Data Unit:	Head
Description:	The number of bulls maintained on the <i>j</i> th farm in each year
In survey?	Table 2.2
Comment:	

### Appendix 3. Analysis of sample size requirements using survey data from Kenya

Guidance from the CDM, referred to in the Smallholder Dairy Methodology suggests that sample surveys should aim to achieve a precision of  $\pm 10\%$  with a 90% confidence interval. The same data can also be used for national GHG inventories, where uncertainty is expressed using a 95% confidence interval (IPCC 2006). Among the survey data collected, animal live weight (LW), energy digestibility of feed and milk yields have strong impacts on gross energy and thus emission factors. This Appendix estimates the sample size required to achieve precision of  $\pm 5\%$  or  $\pm 10\%$  with a 90% and 95% confidence interval when collecting data using two-stage cluster sampling within central Kenya.

If simple random sampling (SRS) is used, then the required sample size ( $n$ ) is:

$$n \geq \left[ \frac{z_{\alpha/2} \sigma}{E} \right]^2 \quad (\text{Eq. A3.1})$$

where

$z_{\alpha/2}$	The z-score separating an area of $\alpha/2$ in the right tail of the standard normal distribution (for 90%, the z-score is 1.645)
$\sigma$	Standard deviation of parameter of interest
$E$	Allowable margin of error around the mean (e.g. 10%)

The equation is sensitive to change in the standard deviation, required precision and confidence level ( $\alpha$ ), and relatively less sensitive to the population size ( $N$ ).

When cluster sampling is used, an adjustment to account for the sampling method can be made by calculating the design effect (DEFF):

$$\text{DEFF} = 1 + (n-1)\rho$$

Where  $n$  = average cluster size and  $\rho$  = intraclass correlation for the desired outcome and

$$\rho = \frac{s_b^2}{(s_b^2 + s_w^2)}$$

where  $s_b^2$  is variance between clusters and  $s_w^2$  is variance within clusters. The sample size calculated for SRS is multiplied by DEFF. When sample size is calculated for all feeding systems together, for each animal sub-category, an adjustment is made to SRS for the average number of animals per household, so that for animal types with less than 1 animal per household, the required number of sampled households would increase. When sample size is calculated for each feeding system, a further adjustment is made to SRS for the proportion of households in the population with the target feeding system.

Tables A3.1-A3.5 show the estimated required sample sizes for different margins of error ( $\pm 5\%$  or  $\pm 10\%$ ) and 90% or 95% confidence intervals.

**Table A3.1 Sample size required to achieve  $\pm 10\%$  with a 90% or 95% confidence interval for live weight data**

	All feeding systems		Zero-grazing		Semi-zero grazing		Grazing	
	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI
Cow	20	28	31	43	79	94	250	321
Heifer	184	262	319	453	617	868	1529	2162
Adult male	3406	4784	2287	3094	13,190	18,893	>20,000*	>20,000*
Growing male	4005	5650	4149	5890	21,789	30,761	13,240	18,656
Male calves	252	353	703	967	1529	2162	3697	4930
Female calves	91	125	131	180	501	701	802	1070

\* required sample size could not be established due to the small sample size in the pilot survey.

**Table A3.2 Sample size required to achieve  $\pm 5\%$  with a 90% or 95% confidence interval for live weight data**

	All feeding systems		Zero-grazing		Semi-zero grazing		Grazing	
	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI
Cow	55	75	86	123	189	251	643	929
Heifer	702	993	1225	1730	2334	3298	5801	8226
Adult male	12,974	18,326	7936	11,164	50,620	71,652	>75,000*	>75,000*
Growing male	1996	>2000*	15,795	22,487	>16,000*	>22,500*	50,551	71,916
Male calves	655	957	1319	1759	1755	2339	9860	14,174
Female calves	283	397	394	558	1603	2254	2140	2942

**Table A3.3 Sample size required to achieve  $\pm 10\%$  with a 90% or 95% confidence interval for feed digestibility**

	All feeding systems		Zero-grazing		Semi-zero grazing		Grazing	
	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI
Cow	12	15	19	24	49	49	110	138
Heifer	23	34	40	60	74	93	254	356
Adult male	379	379	629	880	1333	1333	2713	3617
Growing male	203	304	380	569	909	909	853	1067
Male calves	100	100	174	174	290	290	1222	1222
Female calves	36	45	53	66	160	160	429	536

**Table A3.4 Sample size required to achieve  $\pm 5\%$  with a 90% or 95% confidence interval for feed digestibility**

	All feeding systems		Zero-grazing		Semi-zero grazing		Grazing	
	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI
Cow	24	33	38	52	73	97	248	331
Heifer	57	80	99	139	167	223	661	915
Adult male	910	1213	1635	2138	2000	2667	8138	10851
Growing male	406	558	949	1234	1363	1818	1707	2347
Male calves	150	200	305	392	362	507	1833	2444
Female calves	64	91	105	145	241	281	857	1179

**Table A3.5 Sample size required to achieve  $\pm 10\%$  with a 90% or 95% confidence interval for milk yield**

	All feeding systems		Zero-grazing		Semi-zero grazing		Grazing	
	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI	90% CI	95% CI
$\pm 10\%$	325	462	480	679	1356	1921	2889	4076
$\pm 5\%$	88	124	132	182	367	508	770	1091

## Appendix 4. Descriptive statistics for the primary dataset and the dataset with interpolated missing values

### A4.1 Primary dataset

Table A4.1 shows the herd structure. Within adult males, there was a total of 45 bulls and 5 oxen. All oxen were in the intensive feeding system. Within heifers, 57 out of 280 were reported to be in-calf (i.e. 20.36%), varying between 18.52% under zero-grazing to 23.26% under semi-zero grazing. Among calves, 32.98% of males and 67.02% of females were reported to be still suckling.

**Table A4.1 Distribution of animal numbers (%) by sub-category and feeding system**

	All systems	Zero-grazing	Semi-zero	Grazing only
n	1378	854	371	153
Cow	726 (52.69%)	461 (53.98%)	189 (50.94%)	76 (49.67%)
Heifer	280 (20.32%)	162 (18.97%)	86 (23.18%)	32 (20.92%)
Adult male	50 (3.63%)	31 (3.63%)	11 (2.96%)	8 (5.23%)
Growing male	52 (3.77%)	28 (3.28%)	11 (2.96%)	13 (8.50%)
Male calves	86 (6.24%)	47 (5.50%)	31 (8.36%)	8 (5.23%)
Female calves	184 (13.35%)	125 (14.64%)	43 (11.59%)	16 (10.46%)

### A4.2 Cross-tabulation of breed by feeding system

		Feeding system			Total
		Zero-grazing	Semi-zero grazing	Grazing	
Breed	Holstein-Friesian	630	248	88	966
	Ayrshire	141	69	29	239
	Jersey	25	4	0	29
	Guernsey	21	3	5	29
	Cross-bred unknown	27	26	23	76
	Sahiwal	1	0	0	1
	Boran	1	2	1	4
	Zebu	3	7	10	20
	Other local breed	2	0	0	2
Total		851	359	156	1366

### A4.3 Age (months) of animals with a reported live weight measurement (n=756)

	n	Mean	median	Standard deviation
Cow	275	57.75	54.00	24.39
Heifer	146	21.31	20.00	6.92
Adult male	16	52.13	48.00	15.91
Growing male	23	18.43	18.00	6.00
Male calves	36	5.04	4.50	3.63
Female calves	102	4.38	4.00	2.91

### A4.4 Estimated live weight of different animal sub-categories

	n	mean	median	Standard deviation
Cow	372	365.35	363.86	3.84
Heifer	166	262.92	263.74	98.34
Adult male	20	357.64	334.75	136.37
Growing male	27	241.07	242.42	107.56
Male calves*	41	88.00	82.51	10.79
Female calves*	111	88.29	82.51	12.73

\* after log-transformation to a normal distribution.

### A4.5 Estimated mean live weights of animal sub-categories in each feeding system

		Zero-grazing	Semi-zero grazing	Grazing
Cow	Mean	371.62	353.91	340.21
	s.d.	4.38	3.75	5.06
heifer	Mean	256.49	261.67	243.94
	s.d.	11.46	10.48	9.22
A-male	Mean	321.74	448.33	231.63
	s.d.	1.29	1.44	1.98
G-male	Mean	255.33	231.63	133.44
	s.d.	1.39	1.98	1.43
F-calf	Mean	87.32	98.99	74.89
	s.d.	1.89	2.11	1.61
M-calf	Mean	95.74	91.01	47.60
	s.d.	1.70	1.55	2.66

#### A4.6 Age at first calving (months)

	All	Zero-grazing	Semi-zero grazing	Grazing
n	357	235	93	29
Mean	27.63	27.16	29.34	25.93
Median	26.00	26.00	30.00	24.00
s.d.	5.127	4.957	5.309	4.652

#### A4.7 Parity

	All	Zero-grazing	Semi-zero grazing	Grazing
n	624	395	161	68
Mean	2.44	2.38	2.49	2.63
Median	2.00	2.00	2.00	2.00
s.d.	1.486	1.41	1.628	1.564

#### A4.8 Calving interval (months)

	All	Zero-grazing	Semi-zero grazing	Grazing
n	362	224	101	37
Mean	15.93	15.78	15.83	17.08
Median	14.00	14.00	15.00	15.00
s.d.	4.95	5.22	4.094	5.372

#### A4.9 Milk yield (kg)

	All	Zero-grazing	Semi-zero grazing	Grazing
n	616	396	154	66
Mean*	8.21	9.00	6.99	6.63
Median	8.00	8.50	7.03	6.50
s.d.	4.51	4.71	3.98	3.54

\* after square root transformation

#### A4.10 Lactation days

	All	Zero-grazing	Semi-zero grazing	Grazing
n	360	245	80	35
Mean*	300.04	301.54	288.21	316.57
Median	305.00	305.00	305.00	305.00
s.d.	57.55	49.52	80.16	42.67

## Appendix 5. Analysis of missing values and multiple imputation results

Figure A5.1 Cow missing data pattern

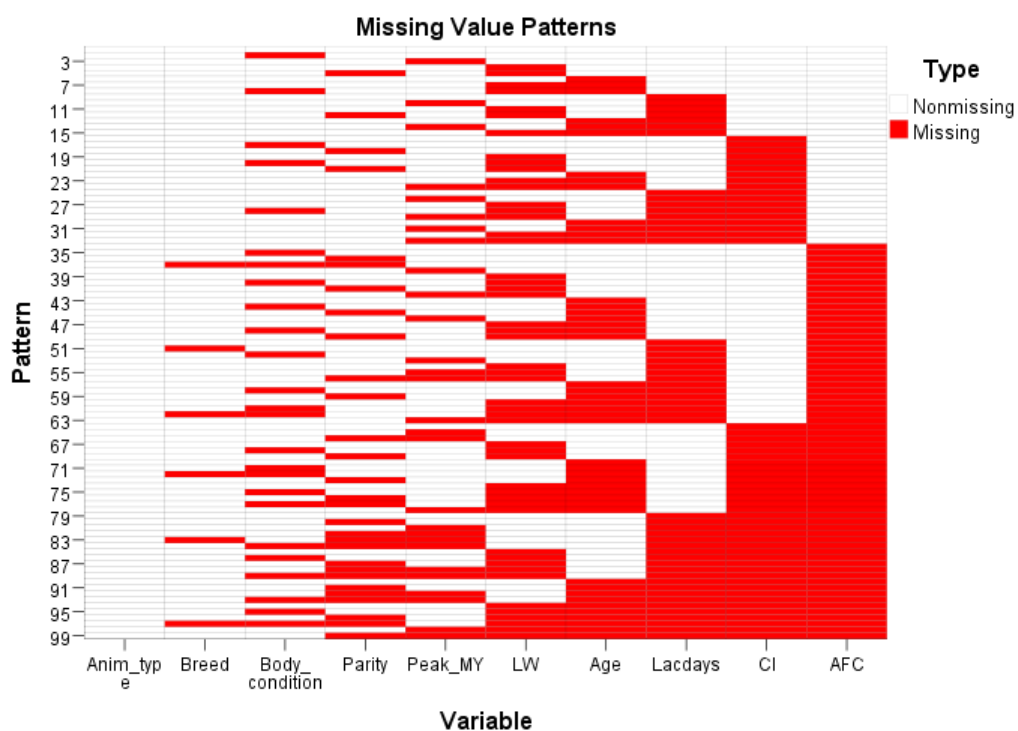
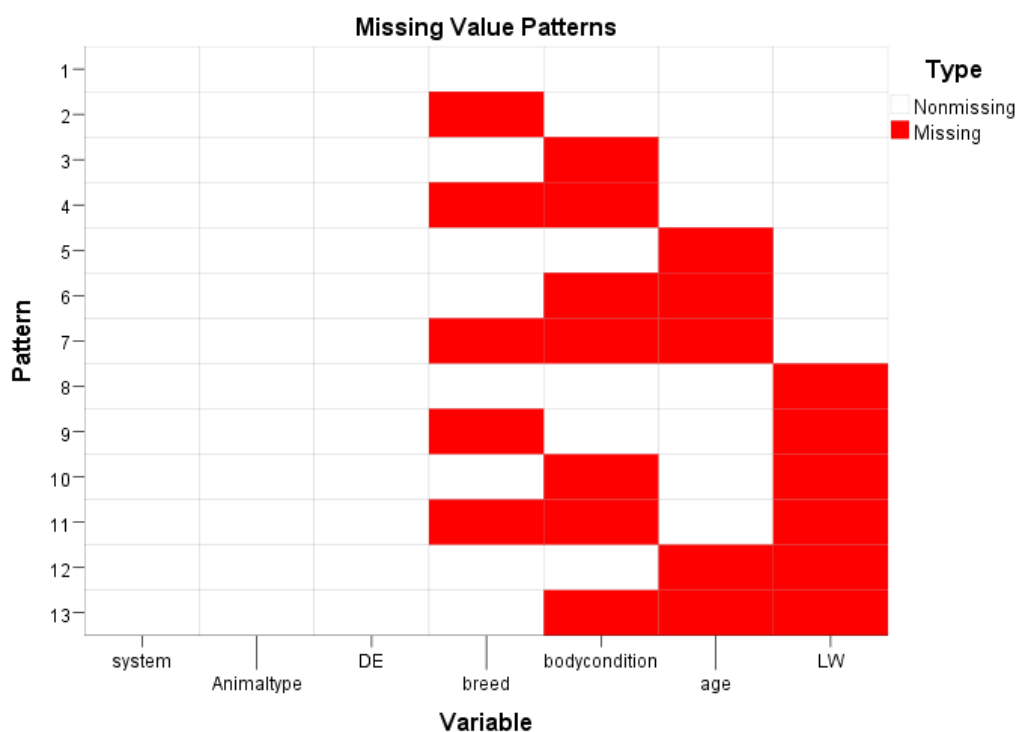


Figure A5.2 Other cattle missing value pattern





**Table A5.1: For cows, results of t-test for difference between means of missing and non-missing data**

Separate Variance t Tests <sup>a</sup>									
		Age	LW	AFC	Parity	Peak_MY	Min_MY	CI	Lacdays
Age	t	.	-1.5	1.6	-.7	1.1	-.2	-.6	-3.0
	df	.	239.9	284.3	597.5	619.2	617.9	352.4	364.2
	P(2-tail)	.	.141	.120	.455	.259	.823	.547	.003
	# Present	374	275	231	339	336	336	205	213
	# Missing	0	111	126	285	286	284	157	156
	Mean(Present)	57.88	365.8344	28.05	2.40	12.8482	5.8744	15.79	283.67
	Mean(Missing)	.	378.0688	27.21	2.49	12.2650	5.9518	16.10	305.08
LW	T	-.2	.	-.6	1.2	-1.9	-.3	-1.5	-1.5
	df	166.7	.	298.2	590.0	580.1	603.9	341.7	329.4
	P(2-tail)	.869	.	.568	.220	.058	.749	.128	.127
	# Present	275	386	215	347	343	343	206	226
	# Missing	99	0	142	277	279	277	156	143
	Mean(Present)	57.75	369.3526	27.63	2.50	12.1335	5.8601	15.58	288.21
	Mean(Missing)	58.24	.	27.94	2.36	13.1290	5.9715	16.38	299.86
AFC	t	.1	.6	.	.4	2.8	1.7	-.9	-1.3
	df	284.3	357.8	.	614.9	620.0	610.6	339.7	359.3
	P(2-tail)	.952	.581	.	.710	.006	.093	.355	.207
	# Present	231	215	357	349	334	334	212	210

	# Missing	143	171	0	275	288	286	150	159
	Mean(Present)	57.94	371.3542	27.75	2.46	13.2365	6.1799	15.73	288.60
	Mean(Missing)	57.78	366.8359	.	2.41	11.8188	5.5944	16.21	298.16
Parity	t	-.6	-.7	-1.6	.	-1.0	-1.3	7.4	-.7
	df	40.7	44.5	7.1	.	42.8	43.9	31.5	23.8
	P(2-tail)	.548	.477	.149	.	.334	.215	.000	.502
	# Present	339	347	349	624	581	579	349	347
	# Missing	35	39	8	0	41	41	13	22
	Mean(Present)	57.63	368.2561	27.66	2.44	12.4876	5.8409	16.04	292.07
	Mean(Missing)	60.37	379.1090	31.88	.	13.8902	6.8829	12.85	303.00
Peak_MY	t	1.0	-.1	-1.4	.4	.	.	-.9	-.4
	df	45.6	49.0	25.4	47.3	.	.	20.1	16.8
	P(2-tail)	.318	.948	.175	.704	.	.	.385	.695
	# Present	336	343	334	581	622	619	343	355
	# Missing	38	43	23	43	0	1	19	14
	Mean(Present)	58.32	369.2404	27.66	2.45	12.5801	5.9048	15.87	292.55
	Mean(Missing)	54.03	370.2474	29.13	2.35	.	9.0000	16.89	297.07
Min_MY	t	.9	-.2	-1.4	.6	-1.2	.	-.9	-.6
	df	45.8	48.9	25.4	50.1	2.2	.	20.1	21.0
	P(2-tail)	.348	.840	.175	.576	.341	.	.385	.585
	# Present	336	343	334	579	619	620	343	353
	# Missing	38	43	23	45	3	0	19	16

	Mean(Present)	58.29	369.0054	27.66	2.45	12.5732	5.9098	15.87	292.48
	Mean(Missing)	54.29	372.1223	29.13	2.31	14.0000	.	16.89	298.06
CI	t	5.2	-.3	-1.2	7.0	4.3	.0	.	-.9
	df	371.9	378.0	296.4	588.8	618.2	583.3	.	343.8
	P(2-tail)	.000	.796	.235	.000	.000	.996	.	.369
	# Present	205	206	212	349	343	343	362	224
	# Missing	169	180	145	275	279	277	0	145
	Mean(Present)	63.56	368.3736	27.49	2.79	13.5627	5.9090	15.93	290.06
	Mean(Missing)	50.99	370.4730	28.14	1.99	11.3720	5.9108	.	296.83
Lacdays	t	.8	-1.2	.5	2.9	1.2	3.9	.4	.
	df	357.0	339.3	322.4	603.1	578.1	616.5	273.2	.
	P(2-tail)	.412	.244	.613	.003	.248	.000	.689	.
	# Present	213	226	210	347	355	353	224	369
	# Missing	161	160	147	277	267	267	138	0
	Mean(Present)	58.78	365.3764	27.87	2.59	12.8403	6.4819	16.01	292.72
	Mean(Missing)	56.69	374.9690	27.59	2.25	12.2341	5.1536	15.79	.
Body_condition	t	.0	.8	-1.3	-1.7	.9	-1.8	.8	-1.0
	df	28.1	18.1	15.7	55.0	60.8	56.6	20.6	41.3
	P(2-tail)	.965	.422	.200	.092	.348	.078	.448	.318
	# Present	348	369	342	575	570	568	343	336
	# Missing	26	17	15	49	52	52	19	33
	Mean(Present)	57.90	369.9609	27.69	2.41	12.6540	5.7924	15.97	291.67

	Mean(Missing)	57.65	356.1498	29.27	2.82	11.7692	7.1923	15.16	303.48
For each quantitative variable, pairs of groups are formed by indicator variables (present, missing).									
a. Indicator variables with less than 5% missing are not displayed.									

**Table A5.2 Pearson Chi-sq values (d.f. in parentheses) for other cattle**

	System	Breed missing	Body condition missing	Age missing	LW missing	AFC missing	Parity missing	Peak MY missing	Min MY missing
Breed missing	7.693 (2)*								
Body condition missing	1.562 (2)	40.309 (1)**							
Age missing	60.653 (2)**	0.212 (1)	0.629 (1)						
LW missing	29.755 (2)**	0.045 (1)	12.681 (1)**	128.436 (1)**					
AFC missing	4.289 (2)	6.838 (1)**	12.169 (1)**	48.9 (1)**	14.045 (1)**				
Parity missing	0.900 (2)	4.857 (1)*	0.121 (1)	14.059 (1)**	10.628 (1)**	81.109 (1)**			
Peak milk yield missing	3.668 (2)	0.000 (1)	2.550 (1)	10.901 (1)**	6.813 (1)**	35.559 (1)**	199.99(1)**		
Min milk yield missing	2.358 (2)	0.001 (1)	2.707 (1)	12.196 (1)**	7.917 (1)**	37.490 (1)**	194.478(1)**	694.113(1)**	
Calving interval missing	1.308 (2)	0.150 (1)	6.162 (1)*	7.562 (1)**	4.052 (1)*	25.471 (1)**	65.398(1)**	48.465(1)**	60.643(1)**

\*\* significant at  $p < 0.01$  \* significant at  $p < 0.05$

**Table A5.2: For non-cows, results of t-test for difference between means of missing and non-missing data**

Separate Variance t Tests <sup>a</sup>				
		age	LW	DE
age	t	.	-4.6	2.1
	df	.	61.6	349.3
	P(2-tail)	.	.000	.034
	# Present	438	321	438
	# Missing	0	47	208
	Mean(Present)	16.6538	193.5584	59.2187
	Mean(Missing)	.	279.4291	58.3157
LW	t	-2.1	.	.2
	df	150.5	.	577.2
	P(2-tail)	.037	.	.847
	# Present	321	368	368
	# Missing	117	0	278
	Mean(Present)	15.4830	204.5256	58.9597
	Mean(Missing)	19.8658	.	58.8860
bodycondition	t	-.3	1.6	-.7
	df	26.9	17.4	50.5
	P(2-tail)	.791	.132	.464
	# Present	413	352	604
	# Missing	25	16	42
	Mean(Present)	16.6030	206.2590	58.8982
	Mean(Missing)	17.4920	166.3913	59.3562
For each quantitative variable, pairs of groups are formed by indicator variables (present, missing).				
a. Indicator variables with less than 5% missing are not displayed.				

**Table A5.4 Pearson Chi-sq values (d.f.) for other cattle**

	System	Breed missing	Body condition missing	Age missing
Breed missing	11.184 (2)**			
Body condition missing	20.204 (2)**	9.226 (1)**		
Age missing	0.341 (2)	2.293 (1)		
LW missing	2.677 (2)	2.198 (1)	6.525 (1)*	147.825 (1)**

\*\* significant at  $p < 0.01$  \* significant at  $p < 0.05$

**Table A5.5: Comparison of descriptive statistics for primary and imputed datasets for cows**

Statistic	Age (months)	LW (kg)	AFC (months)	Parity (number)	Peak MY (L)	Min MY (L)	CI (months)
Primary sample mean	57.69	369.65	27.69	2.44	12.57	5.91	15.85
Imputed sample mean	55.63	366.34	27.42	2.39	12.32	5.74	15.57
Discrepancy in mean	2.06	3.31	0.27	0.05	0.25	0.17	0.28
Primary s.d.	24.49	79.06	4.98	1.49	6.48	4.33	4.92
Imputed s.d.	19.00	62.90	3.84	1.41	6.16	4.08	3.64
Discrepancy in s.d	-5.49	-16.16	-1.14	-0.08	-0.32	-0.25	-1.28

Note: means differ from those reported in Appendix 4 because of the deletion of some cases before imputation.

**Table A5.6: Comparison of descriptive statistics for primary and imputed datasets for other cattle types**

	Adult males		Growing males		Heifers		Female calves (2 m - 1 yr)		Male calves (2 m - 1 yr)		Female calves (<2m)		Male calves (<2 m)	
Statistic	Age (mont hs)	LW (kg)	Age (mont hs)	LW (kg)	Age (mont hs)	LW (kg)	Age (mont hs)	LW (kg)	Age (mont hs)	LW (kg)	Age (mont hs)	LW (kg)	Age (mont hs)	LW (kg)
Primary sample mean	57.69	369.65	55.04	373.24	18.78	217.72	5.51	137.03	6.97	119.55	1.91	54.90	1.46	64.86
Imputed sample mean	55.63	366.34	53.91	370.21	19.31	217.52	5.50	130.28	6.72	117.25	1.90	50.73	1.36	65.86
Discrepancy in mean	2.06	3.31	1.13	3.03	-0.53	0.20	0.01	6.75	0.24	2.30	0.01	4.18	0.10	-1.00
Primary s.d.	24.49	79.06	20.52	148.15	5.63	82.05	2.50	73.00	2.73	59.92	0.67	26.92	0.58	25.69
Imputed s.d.	19.00	62.90	15.73	99.32	5.28	63.04	2.19	54.53	2.36	43.92	0.59	21.54	0.52	18.91
Discrepancy in s.d.	-5.49	-16.16	-4.79	-48.83	-0.35	-19.01	-0.31	-18.48	-0.37	-16.00	-0.08	-5.38	-0.05	-6.77

Note: means differ from those reported in Appendix 4 because of the deletion of some cases before imputation.

## Appendix 6: Selected summary input data and results from the baseline data analysis

**Table A6.1 Data sources for feed dry matter (DM) content, feed digestibility (DE) and crude protein content (CP) of feed**

Feed type	Dry matter content (%)			Digestibility (DE as % of GE)			Crude protein content (%)			Data sources
	fresh	dry / hay	silage	fresh	dry / hay	silage	fresh	dry / hay	silage	
Natural pasture	33.0			60.2			11.0			Onyango et al. 2016
Napier grass	20.0	89.3	23.0	58.7	55.3	53.7	8.0	11.1	5.35	Onyango et al. 2016; Feedipedia; Laswai et al. 2013
Blue buffalo grass	21.7	91.5	23.0	54.2	56.8	56.15	7.1	9.0	10.65	Feedipedia; Kirwa et al. 2015
Kikuyu grass	28.3	93.0	37.0	66.0	56.0	56.15	10.5	12.0	12.0	Laswai et al. 2013; FEAST database; Feedipedia
Star grass	29.5	93.0	37.0	55.8	50.1	56.15	9.5	10.2	10.65	Laswai et al. 2013; FEAST database; Feedipedia
Guinea grass	30.2	89.8		55.3	53.9		7.22	12.0		Laswai et al. 2013; Feedipedia
Giant setaria	22.2	86.0		60	55.2		9.1	9.9		Feedipedia; Hacker & Jones 1969;
Giant panicum	22.7	89.8		55.3	53.9		11.2	9.1		Feedipedia
Boma Rhodes	23.6	86.4	22.0	57.7	55.6	58.6	4.96	10.1	6.15	Laswai et al. 2013; Feedipedia
Calliandra	36.2	93.0		68.3	50		18.9	25.8		Laswai et al. 2013; FEAST database
Lucerne	25.0	85.4	31.0	65.5	58.4	62.1	18.4	16.3	19.1	Laswai et al. 2013; Feedipedia
Desmodium	22.2	85.2		55.6	49.6		17	12.8		Laswai et al. 2013; Feedipedia
Lucaenia	26.0	85.2		73.3	50		20	22.65		FEAST database; Feedipedia; SSA Feeds database
Sesbania	23.3	90.6		78.9	23.3		22.5	21.63		Laswai et al. 2013; Feedipedia; SSA Feeds database
Weeds	19.5			83			13.77	13.77	13.77	Nyaata et al. 2000



Cabbage	6.0	11.0		50.9	50.9		16	16	16	FEAST database
Green maize stovers	23.3	92.9	35.0	64.2	52.6	69.4	7.9	10.1	7.2	Feedipedia; FEAST database; Laswai et al. 2013
Green maize cob, kernel, stover	28.9	87.0	35.0	62.6	52.6	69.4	6.9	3.7	7.2	Laswai et al. 2013; FEAST database
Dry maize stovers	92.9	92.9	35.0	52.6	52.6	69.4	10.1	10.1	7.2	Laswai et al. 2013; FEAST database
Dry maize cob, kernel, stover	87.0	87.0	35.0	52.6	52.6	69.4	5.9	5.9	7.2	Laswai et al. 2013; FEAST database
Maize thinnings	38.0	92.9		64.2	52.6		10.2	3.7		Laswai et al. 2013; Feedipedia
Wheat residue	91.0	91.0	34.0	45.2	45.2		4.2	4.2	13	Feedipedia; FEAST database
Oat residue	89.6	89.6		44.7	44.7		3.6	3.6		Feedipedia; FEAST database
Rice residue	92.8	92.8		46.5	46.5		4.2	4.2		Feedipedia
Sorghum residue	85.0	85.0	20.0	49.3	49.3	60.3	5.0	5.0	9.0	FEAST database; Feedipedia; Tjandraatmadja et al. 1993
Bean residue	12.0	88.0		51.1	51.1		7.1	7.1		FEAST database; Feedipedia
Cow pea residue	20.9	90.0		68.0	51.1		18.1	14.8		FEAST database; Feedipedia
Sweet potato vines	26.0	88.5		52.5	61.8		10.0	13.2		Onyango et al. 2016; Feedipedia
Potato peelings	15.0	15.0		63.3	63.3		7	7		FEAST database
Banana stems and residue	8.5	94.3		52.5	61.8		10.5	13.2		Onyango et al. 2016; Feedipedia
Vetch	19.3	90.1		66.7	60.9		23.0	19.7		Feedipedia
Silage (maize)	35.0	35.0	35.0	69.4	69.4	69.4	7.2	7.2	7.2	FEAST database; Laswai et al. 2013
vegetable waste	86.5			58.6			18.9			Munguti et al. 2012
Commercial dairy meal	87.0			64.6			18.2			Calculated based on dairy meal composition from FAO and NZAGR (2017)

Home made dairy meal	88.0			72.7			17.8			Calculated based on dairy meal composition from ILRI (n.d.)
bran (wheat)	87.0			71.4			16.0			Feedipedia; Laswai et al. 2013
bran (maize)	89.0			72.4			11.4			Feedipedia; Laswai et al. 2013
maize germ	92.0			80.8			14.9			Feedipedia
sesame seed by product	92.8			80.3			37.7			Feedipedia
Cotton seed cake	93.6			64.0			42			Feedipedia; Laswai et al. 2013
sunflower seed meal	91.8			67.5			35.7			Laswai et al. 2013; Feedipedia
molasses	72.5			76.6			4.1			Laswai et al. 2013; Feedipedia
Wheat grain	89.1			85.7			12.6			Feedipedia
Wheat pollard	88.2			82.1			15.2			Feedipedia
Soya bean meal	87.9			92.2			51.8			Feedipedia
Fish meal	92.2			95.9			70.6			Feedipedia
Dicalcium Phosphate	95.9			0			0			SSA Feeds database
Limestone	95.9			0			0			SSA Feeds database
Mineral Premix.	95.9			0			0			SSA Feeds database

**Table A6.2: Average diet composition for animals in the zero grazing feeding system**

Type	Nap ier	Ot her gra ss	Ma ize	Graz ed past ure	Prot ein fodd er	Concent rate	Ma ize ger m	Mine rals	Ot her
Cow	22. 6%	8.6 %	29. 3%	0%	0.9%	13.5%	4.7 %	4.4%	15. 6%
Heif er	22. 3%	8.8 %	35. 0%	0%	1.2%	6.7%	3.5 %	6.2%	16. 3%
Adul t male	28. 8%	4.5 %	34. 7%	0%	2.6%	4.6%	4.7 %	2.9%	17. 2%
Grow ing male	19. 6%	9.9 %	34. 5%	0%	1.1%	2.6%	2.8 %	8.6%	20. 9%
Calv es	28. 6%	8.7 %	31. 8%	0%	1.5%	3.3%	2.1 %	4.3%	19. 8%

**Table A6.3: Diet composition for animals in the semi-zero grazing feeding system**

Type	Nap ier	Ot her gra ss	Ma ize	Graz ed past ure	Prot ein fodd er	Concent rate	Ma ize ger m	Mine rals	Ot her
Cow	11. 6%	3.7 %	21. 9%	32.3 %	0%	9.9%	2.9 %	4.5%	12. 9%
Heif er	10. 5%	4.3 %	30. 6%	23.7 %	3.5%	5.4%	4.8 %	4.1%	13. 2%
Adul t male	20. 8%	2.5 %	24. 5%	30.6 %	0%	2.1%	2.5 %	1.2%	15. 9%
Grow ing male	3.2 %	3.3 %	11. 5%	52.2 %	0%	1.6%	6.0 %	11.6 %	10. 7%
Calv es	13. 6%	6.3 %	34. 5%	26.0 %	1.0%	2.6%	1.1 %	2.4%	12. 6%

**Table A6.4: Diet composition for animals in the grazing only feeding system**

Type	Napier	Other grass	Maize	Grazed pasture	Protein fodder	Concentrate	Maize germ	Minerals	Other
Cow	8.0 %	6.2 %	16.5 %	39.3 %	0.6 %	11.9 %	1.2 %	3.2 %	13.2 %
Heifer	5.9 %	4.3 %	26.7 %	28.4 %	1.4 %	7.6 %	0.9 %	2.3 %	22.3 %
Adult male	3.9 %	9.9 %	4.8 %	45.5 %	0 %	3.7 %	0 %	7.6 %	24.6 %
Growing male	14.9 %	2.5 %	16.6 %	29.8 %	0.8 %	12.2 %	0.7 %	7.4 %	14.9 %
Calves	10.2 %	8.9 %	23.7 %	36.6 %	1.1 %	8.2 %	0 %	3.4 %	7.9 %

**Table A6.5: Annual average feed digestibility (% , mean  $\pm$ s.e.)**

	All systems	Zero-grazing	Semi-zero	Grazing only
N	1378	854	371	153
Cow	59.48 $\pm$ 0.65	59.42 $\pm$ 0.20	59.63 $\pm$ 0.66	59.43 $\pm$ 0.59
Heifer	59.35 $\pm$ 0.31	59.38 $\pm$ 0.41	59.43 $\pm$ 0.50	58.99 $\pm$ 1.16
Adult male	57.30 $\pm$ 0.74	57.07 $\pm$ 0.82	57.60 $\pm$ 1.41	57.80 $\pm$ 2.90
Growing male	59.06 $\pm$ 0.60	58.14 $\pm$ 0.74	61.07 $\pm$ 1.27	59.32 $\pm$ 1.38
Male calves	58.87 $\pm$ 0.42	57.94 $\pm$ 0.54	59.82 $\pm$ 0.64	60.69 $\pm$ 1.86
Female calves	58.72 $\pm$ 0.31	58.84 $\pm$ 0.38	58.31 $\pm$ 0.56	58.94 $\pm$ 1.40

**Table A6.6 Enteric fermentation emission factors estimated (kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>, mean  $\pm$ s.e.)**

	All	Zero-grazing	Semi-zero	Grazing
Cow	79.88 $\pm$ 0.80	81.84 $\pm$ 1.03	75.88 $\pm$ 1.44	78.05 $\pm$ 2.25
Heifer	46.97 $\pm$ 0.87	46.60 $\pm$ 1.21	46.69 $\pm$ 1.31	49.49 $\pm$ 2.86
Adult male	50.67 $\pm$ 2.02	47.42 $\pm$ 2.23	57.85 $\pm$ 4.45	52.26 $\pm$ 6.04
Growing male	33.57 $\pm$ 1.11	34.29 $\pm$ 1.22	34.86 $\pm$ 2.89	30.84 $\pm$ 2.57
Male calves	20.05 $\pm$ 0.76	20.79 $\pm$ 1.04	19.45 $\pm$ 1.21	17.63 $\pm$ 2.81
Female calves	27.15 $\pm$ 0.99	27.06 $\pm$ 1.21	27.96 $\pm$ 2.17	25.71 $\pm$ 2.75

**Table A6.7: Manure management methane emission factors estimated (kg CH<sub>4</sub> head<sup>-1</sup> year<sup>-1</sup>, mean  $\pm$ s.e.)**

	All	Zero-grazing	Semi-zero	Grazing
Cow	6.49 $\pm$ 0.22	6.88 $\pm$ 0.31	6.57 $\pm$ 0.35	3.99 $\pm$ 0.25
Heifer	2.87 $\pm$ 0.11	3.04 $\pm$ 0.16	2.83 $\pm$ 0.2	2.10 $\pm$ 0.21
Adult male	3.12 $\pm$ 0.36	3.14 $\pm$ 0.34	4.27 $\pm$ 1.21	1.52 $\pm$ 0.25
Growing male	2.24 $\pm$ 0.36	2.64 $\pm$ 0.57	2.73 $\pm$ 0.78	0.92 $\pm$ 0.18
Male calves	1.41 $\pm$ 0.16	1.64 $\pm$ 0.26	1.21 $\pm$ 0.2	0.63 $\pm$ 0.14
Female calves	1.85 $\pm$ 0.12	1.84 $\pm$ 0.15	2.12 $\pm$ 0.28	1.21 $\pm$ 0.25

**Table A6.8: Feed emission factors used**

Fodder / feed / supplement type	kgCO <sub>2</sub> e/kg DM feed	Data source
Napier grass	0.028	Calculations using baseline survey data
Blue buffalo grass	0.028	Calculations using baseline survey data
Kikuyu grass	0.028	Calculations using baseline survey data
Star grass	0.028	Calculations using baseline survey data
Guinea grass	0.028	Calculations using baseline survey data
Giant setaria	0.028	Calculations using baseline survey data
Giant panicum	0.028	Calculations using baseline survey data
Boma Rhodes	0.028	Calculations using baseline survey data
Calliandra	0	FAO (2017)
Lucerne	0.028	Calculations using baseline survey data
Desmodium	0.028	Calculations using baseline survey data
Lucaenia	0	FAO (2017)
Sesbania	0	FAO (2017)
Other grasses	0.028	Calculations using baseline survey data
Weeds	0	Assuming only manual harvesting
Cabbage	0.320	Clune et al. (2016)
Green maize stovers	0.038	Calculations using baseline survey data
Green maize cob, kernel, stover	0.057	Calculations using baseline survey data
Dry maize stovers	0.038	Calculations using baseline survey data
Dry maize cob, kernel, stover	0.057	Calculations using baseline survey data
Maize thinnings	0.057	Calculations using baseline survey data
Wheat residue	0.155	LEAP database
Oat residue	0.068	Calculations using baseline survey data
Rice residue	0.475	Calculations using baseline survey data
Sorghum residue	0.068	Calculations using baseline survey data
Bean residue	0.012	Pilbeam (1996), Katungi et al. (2010)
Cow pea residue	0.012	Assumed same as bean residue
Sweet potato vines	0.074	LEAP database (assumed same as cassava vines)

Potato peelings	0.120	FEEDPRINT
Banana stems and residue	0.064	Tock et al. (2010), Svanes & Aronsson (2013)
Vetch	0.028	Calculations using baseline survey data
Silage (maize)	0.060	Calculations using baseline survey data
Vegetable waste	0.032	Calculations using baseline survey data
Commercial dairy meal	1.669	Calculated using composition from FAO & NZAGRC (2017) and EFs from FEEDPRINT
Home made dairy meal	1.395	Calculated using composition from ILRI (n.d.) and FEEDPRINT
Bran (wheat)	0.849	FEEDPRINT
Bran (maize)	1.295	FEEDPRINT
Maize germ	1.110	FEEDPRINT
Sesame seed by product	2.250	FEEDPRINT
Cotton seed cake	1.958	FEEDPRINT
Sunflower seed meal	0.954	FEEDPRINT
Molasses	0.781	FEEDPRINT
Wheat grain	0.155	LEAP database
Pollard	0.849	FEEDPRINT
Soya bean meal	0.901	Dalgaard et al. (2008)
Fish meal	1.400	FEEDPRINT
Dicalcium Phosphate	0.938	Pelletier et al. (2014)
Limestone	0.043	Pelletier et al. (2014)
Mineral Premix.	0.800	Sonesson et al. (2009)

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